

PLASTICS IN INDUSTRY

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PLASTICS IN INDUSTRY

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INTRODUCTION

THIS book has been compiled in order that it may be read by the industrialists of the world. The writers hope, with due modesty, that by such reading many confused ideas regarding plastics and the plastics industry will be clarified and that there will be presented to the eyes of the aforesaid industrialists a comparatively new series of materials of construction worthy of their examination and, finally, worthy of their employment for series or mass production. There is, indeed, much that is puzzling in an industry that can produce at will such diverse objects as radio cabinets, milk bottles, bearings for metal rolling-mills, coffins, bottle caps, aeroplane parts and life-size cast statues.

The present century is one of intense scientific development. But it is also productive, on occasion, of considerable loose thinking and sensationalism : with the result that we have had thrust upon us by the ubiquitous journalist the idea that this is the Plastics Age, conveying some division of history equivalent to the Stone Age or Bronze Age, and that ships and shoes and sealing wax and imitation cabbages and kings' crowns are all made of plastics. As well call this the Age of Concrete or Dyestuffs or Textiles merely because considerable quantities are used. Such talk is foolish, and it often becomes dangerous, as when the journalist announces to the world the discovery of a new chemical substance and adds or infers that, since it is made from abundant raw materials, it must necessarily be cheap. A synthetic substance may be cheap. On the other hand, it may be very expensive.

To take an example. The daily papers have announced to the world that synthetic rubber is made from acetylene and that since carbide from which acetylene is made is a penny or so per pound, therefore the motor-cars of the world will soon be running on synthetic tyres that cost next to nothing. This is a distortion of the present facts, for synthetic rubber is being sold at about 4s. per lb. and will probably never (certainly not in the next twenty-

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five years) reach a price equal to that of natural rubber, say 8*d.* to 1*s.* per lb. The manufacture of synthetic rubber entails a large number of very complicated expensive chemical steps, comprising the use of intricate and expensive plant and supervision. Moreover, as a raw material for tyre making it is little, if at all, superior to natural rubber—it finds an important place at its high price for *other* purposes where it is superior to rubber in certain ways. For example, rubber dissolves or swells badly in certain oils and so cannot be used for making pipes and valves for carrying such oils. Synthetic rubber is not affected by many oils, so that we have here a new material of construction of great value to the industrialist for a purpose that natural rubber cannot satisfy and which is, in fact, worth the 4*s.* per lb. that he pays.

The urgent thing to realise is that one should not regard prime cost as a prime consideration. It is the character or suitability of the material for definite purposes that should first be examined, when sundry advantages may be discovered—and real low cost re-found.

The secret with regard to plastics lies first in the fact that they are easily moulded into complicated shapes and secondly they possess many properties presenting outstanding advantages for many purposes.

The manufacturers of the world must realise the following few facts illustrated by one particular type of plastic :

An object, when made from metal, may have to be built up from several separate pieces, the very making of which can entail a waste of 20–50 per cent. of metal. In the building it is crimped, soldered, screwed or welded, sand-blasted and degreased, chromium-plated or painted ; varnished, buffed or polished before it can be sold to the customer. A simple metal object may undergo a dozen processes of preparation. The same object in plastics, polished and coloured throughout, can be turned out one, two or a dozen at a time in two minutes with virtually no waste of raw material, and only needing packing to be ready for the customer. Moreover, plastics often allow of simpler designs. We leave the industrialist to imagine what economic value this may have on his business. A plastic material at 1*s.* per lb. can sometimes be cheaper than sheet steel at 2*d.* per lb.

Because of the characteristics and properties of plastics the telephone has been transformed from a metal horror to a shape

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of considerable æsthetic value and supreme mechanical and electrical merit ; the motor-car has been lightened in weight, made safer, more colourful and probably less costly ; machinery has been fitted with silent gears and bearings that outlast the toughest phosphor bronzes ; art has been enriched by new materials for fashioning ; social life has been completely changed by the introduction of a vast range of articles of domestic utility of low price and considerable beauty that has greatly accelerated the spending tendencies of the masses.

But there is more in this book, the writers hope, than mere enthusiasm for plastics because they are new materials. They hope to give a real picture, too, of the limitations of plastics—this they believe is necessary to the well-being of the industry.

When the strength or hardness or weight of steel is essential, plastics cannot be employed. When an electrical conductor or heat conductor is required, plastics, again, cannot be used. When great sizes in one piece are required, plastics cannot be used, for, at present, there are limits to the size of moulds or size of the raw material (if in sheet form) that can be obtained. Mere size may eventually and probably will be overcome, other properties may be improved, others cannot be changed. The plastics industry does not offer a panacea for all ills, nor a constructional material for all purposes.

If the writers succeed in their object of giving the reader a true picture of plastics, they have every hope that the world will thereby be enriched.

CHAPTER I

DEFINITIONS AND THE PLASTICS INDUSTRY

WHAT is the plastics industry and what are the materials it deals with? There is considerable confusion in the mind of the general public and even many technically trained. This lack of understanding is not due to any absence of intelligence on the part of enquirers, but rather because of the necessity for sound definitions within the plastics industry itself.

Let us try and explain the general difficulty by beginning with a theoretical definition of plastics.

A plastic material is one that, under pressure, will change its shape and, on release of that pressure, will retain its new shape.

But this definition is obviously too wide for our purpose, since it includes putty or clay and even steel and most metals.

The real clue is given by the statement that the plastics industry manufactures rigid or semi-rigid units of construction of considerable mechanical strength, made from plastic organic materials exclusively and not metallic or mineral compounds. Where a metallic or mineral compound does become an ingredient it is merely as a filler for the main organic binder, so as to give the latter special properties.

In other words, the word "plastics" is governed not by any theoretical physico-chemical definition, but by the very practical limits of the output of a branch of engineering—the plastics industry. Plastics are defined by the history of the plastics industry.

We may consider that the industry really began with the introduction of celluloid (about 1875), casein (1905) and bitumen. The last two named were, at the beginning of the twentieth century, enjoying the doubtful privilege of being called "composition"—a name which meant little but was given to almost anything that was of an indeterminate character and not made from metal, wood or stone.

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Celluloid was used to make combs, dolls, toys, collars and knife handles from moulded celluloid by one or two firms in the great industrial countries, Germany, Great Britain, U.S.A. and Japan. When casein came on the scene, it could be worked in almost the same way and was made into very similar articles—combs, buttons, knife handles, fountain pens, billiard balls, etc. Often the celluloid factories also made casein plastics, and with the passing of time they became expert in the moulding of such materials. The extrusion of casein powders and the shaping of celluloid rod and sheet became a purely engineering job.

Bitumen and asphalt tell another story. When the electrical industry expanded, as the result of ambitious schemes of electrification throughout the country, there arose a demand for insulating materials other than ebonite and mica. Coal tar residues and petroleum asphalts were found to give very good results, especially when mixed with asbestos, silica dust, etc., and, moreover, were found to be amenable to shaping under pressure and low heat into rigid insulators of all types. Yet another fillip was given to this type of "composition" when the motor-car industry needed a rigid box to contain acid and so become an accumulator box. All these insulators and boxes were moulded in steel dies under pressure, and, here again, with the passage of time, the concerns that undertook bitumen moulding became very expert at the job, and this, in turn, like the celluloid and casein industry, assumed the aspect of engineering industries.

When Bakelite, the first phenol-formaldehyde synthetic resin, was first introduced, it was found to be an excellent insulator and, moreover, mouldable into useful and complicated shapes. Quick recognition of the potentialities of Bakelite was made by the electrical industries using bitumen and ebonite dust. It was soon realised that the new synthetic resins were readily adaptable to the moulding technique with heated dies. It was the logical sequence of events. When these works expanded, new ideas or, rather, new applications came in abundance from the outside world—ash trays, switch covers, cigarette boxes, telephone receivers, and a thousand other articles. The simple moulders of celluloid toys or bitumen insulators were able to undertake the manufacture of very complicated mouldings for almost any industry, light or heavy.

To-day the plastics industry has at least a dozen chemically

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different raw materials, all organic in character, at its disposal and all mouldable under heat and pressure.

It may be argued that rubber is a true plastic. This is so, but the fact remains that the rubber industry, even though it is a moulding industry, is not considered to be in the plastic industry for purely economic reasons—it is a self-contained industry, does not employ the same high-pressure moulding machinery (except in the case of tube or rod extrusion) and does not utilise synthetic resins as a raw material. The plastics industry, in its turn, does not mould tyres and, in fact, does not use rubber as a raw material.

On the other hand, synthetic rubber is considered to be in both industries—obviously in the case of the rubber industry and in the plastics industry because many rubber-like synthetic materials are utilised by certain plastic moulders.

Similarly, a section difficult of definition is the rayon industry. This cannot be considered to be of the plastics industry since textiles form an enormous industry on their own. Yet the raw materials, viscose or cellulose acetate, are used also as film and sheet, and the manufacturer and shaper of such material is considered to be in the plastics industry.

The segregation is noted in the technical journals on plastics which generally omit mention of natural rubber and textiles.

It may be taken then that the plastics industry is one that in a variety of engineering processes, high-pressure moulding, injection moulding, extrusion into rods or tubes, shaping or forming of sheet, impregnation of paper, fabric and wood, utilises a range of organic substances, largely synthetic, among which the following are best known :

Celluloid.	Phenol-formaldehyde	Acrylic resins.
Cellulose acetate.	resins.	Vinyl resins.
Casein.	Urea-formaldehyde	Polystyrenes.
Bitumen.	resins.	Synthetic rubber.
	Soya bean phenol-	
	formaldehyde resins.	

CHAPTER II

THERMO-PLASTIC AND THERMO-SETTING RESINS

CHIEF PLASTICS—THEIR MANUFACTURE AND PROPERTIES

BEFORE proceeding to the main argument of this book, the industrial applications of plastics, it is advisable and indeed necessary to obtain some insight of their source, their manufacture and properties and, finally, the manner in which they are processed by moulding and other means into the final forms in which they appear on the market.

This insight of raw material manufacture is advisable, not merely because it is a fascinating subject, but also because it is necessary to an understanding of the after-processing adopted and of the reasons for choosing certain plastics for certain purposes.

Nevertheless, the industrial applications of plastics and their portrayal to the potential industrial user and commercial trader is the chief function of this book. And since it is not a chemical or physical treatise on plastics, the methods of manufacture are described but very generally, shortly, and, as far as possible, in a non-technical manner. To those who seek pure chemical knowledge of the subject there are many text-books available.

As we have already stated in the opening chapter, the modern plastics under discussion are organic compounds which are distinguished from metallic or other inorganic substances by being derived from carbon. Organic substances are typified by all living or dead carbonaceous matter: coal, flesh, wood and other plant life, petroleum; fats, etc. They also include a host of synthetic, semi-synthetic or derived compounds obtained by chemical processes from the aforementioned natural organic raw materials. Among synthetic materials are dyestuffs, explosives,

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fuels, pharmaceutical products, solvents, etc. To these we now add the raw materials of the comparatively new plastics industry.

To the economic geographer the study of plastics is interesting, since, given that plastics production is as nationally important as we believe it to be, we have only to indicate those countries which possess (a) primarily an abundance of coal and/or petroleum and, secondarily, wood, cotton, etc., and (b) the technical skill and machines to process them, as being those which fortune will favour especially in this new industrial effort.

Plastics are so varied in composition that it is desirable, for the sake of clarity, to divide them into sections. The method adopted here is quite general and relates to two broad divisions dependent on a simple physical distinction. This distinction finds its echo in the methods of processing the two divisions.

1. Those which are softened, moulded or shaped by pressure, with or without heat, *and whose finished hardened shape can be re-softened by heat and re-moulded.*

Such plastics are the heat-softening type and are generally called *thermo-plastics*.

2. Those which, in their original condition, flow and can be moulded by heat and pressure, but which, once in their finished shape or "cured" condition, *cannot be re-softened or re-moulded.* This final moulded shape remains rigid and hard when heated.

Such plastics are the heat-hardening type and are generally called *thermo-setting plastics*.

The best known under each of these divisions are—

Thermo-plastics.

Cellulose compounds.
Bitumen.
Casein.
"Styrene" resins.
"Vinyl" resins.
"Acrylic" resins.
Synthetic rubbers.

Thermo-setting Plastics.

Phenol-formaldehyde resins.
Soya-phenol-formaldehyde resin.
Urea-formaldehyde resins.
Melamine-formaldehyde resins.

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THERMO-PLASTICS

Cellulose Plastics.

These comprise a fairly wide range of materials made from cellulosic materials, such as cotton, paper, wood, etc., by interaction with chemicals.

Cellulose Nitrate, better known as *Celluloid*, is the oldest of the plastics, having been discovered by an Englishman, Alexander Parkes, in 1864. He did not concern himself with its commercial application, but some ten years later its manufacture began in the great industrial countries, Great Britain and U.S.A., and later in Germany and France.

Manufacture.—Purified cotton linters are stirred with a mixture of nitric and sulphuric acids. The cellulose of the cotton combines with the nitric acid forming cellulose nitrate with the liberation of water which is absorbed by the sulphuric acid. The resulting cellulose nitrate pulp, after removal of excess acid, is stabilised by boiling with water and separated in a centrifuge. At this stage the cellulose nitrate still retains its “cottony” or fibrous form. To produce from this celluloid plastic, it is first treated with alcohol and then kneaded with camphor, rolled and calendered into sheets; consolidation of a number of sheets under pressure results in the production of solid blocks. Without the addition of dyes or pigments, celluloid is nearly water white and transparent, but by such addition it can be made coloured and transparent, coloured and opaque or of variegated colours at will.

Forms of Celluloid.—From these solid blocks, large sheets from $\frac{1}{1000}$ in. in thickness upwards can be produced by slicing-machines. Celluloid also appears on the market in the form of rods and tubes.

Most readers will have handled celluloid in some form or other and are therefore able to visualise most of its properties. Apart from other reasons it is described first, so that comparisons with other similar plastics will be easier.

Properties and Uses of Celluloid.

1. High inflammability.
2. Ease of moulding.

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3. Tensile strength, about $2\frac{1}{2}$ –5 tons per sq. in.
4. High impact strength, 0.3–1.0.
5. Water absorption, 1–3 per cent. by weight in twenty-four hours' immersion.

The first property immediately limits the uses of celluloid to those where contact with fire is extremely unlikely. It is thus confined, or should be confined, to fancy goods for the dressing-table and bathroom and to objects such as fountain-pens, cycle pumps and mudguards, knife handles and ping-pong balls. Cinematograph film is almost always made from celluloid, and large numbers of children's dolls are also fabricated therefrom. Some blame has been laid at the door of manufacturers for producing dolls of this material. While we have no desire to minimise any danger that exists, it must be pointed out that casualties are few, and there appears to be far more danger in crossing a road. Nevertheless, it is to be hoped that all such dolls will be replaced one day by non-inflammable material.

Cellulose Acetate.

Chemically, cellulose acetate has been known almost as long as celluloid, but it was not until about 1914 that manufacture assumed reasonable proportions; it was then used not as a mouldable plastic, but as a dope for producing lacquers for aircraft. It was not until 1924 that sheet and, later, moulding powders became known to the market. The great attractiveness of acetate lies in the fact that it is non-inflammable, compared with celluloid, and perfectly safe. Otherwise, in appearance, strength and mouldability there is little to choose between the two materials.

Manufacture.—Cellulose acetate is manufactured in a manner closely resembling that of celluloid. The chief raw material is cellulose, and since cotton is the purest form of cellulose it is almost always employed. Some success has been obtained by using other forms of cellulose, e.g. wood pulp and even straw, but especial purifying methods must be adopted, otherwise the quality of the finished cellulose acetate is affected.

Cellulose is treated with acetic acid and a derivative of acetic acid called acetic anhydride. The acetate resulting from this reaction is in a syrupy form, from which a white powdery or

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flaky material is obtained. This is then dissolved in a mixer with organic solvents and plasticisers, and a plastic dough is obtained containing 50 per cent. or more of cellulose acetate. This dough is then rolled on hot rollers to reduce the volatile solvents and used to make sheets, tubes, rods or moulding powder. For the production of tubes and rods the dough is extruded directly. Sheets are made by the slicing of solid blocks (up to 8 in. thick), obtained by consolidating the rolled dough in hydraulic presses and then cooling.

Properties.—In appearance, feel, hardness, toughness, etc., there is little difference between celluloid and cellulose acetate. The main properties of cellulose acetate are—

1. Specific gravity = 1.27.
2. Non-inflammability.
3. Tensile strength, 3–5 tons per sq. in.
4. Impact strength $\left\{ \begin{array}{l} \text{sheet, about } 0.3\text{--}0.5 \\ \text{moulded, about } 0.9\text{--}1.5 \end{array} \right\}$.
5. Water resistance, 1–3 per cent. in twenty-four hours.

The low water resistance is a drawback, but occasional contact with water has no effect on cellulose acetate. The general excellent properties allow the material to be very widely used. It does not yellow like cellulose nitrate and, consequently, has replaced the latter in many directions. It possesses high resistance to petroleum, vegetable oils, dilute acids and alkalis.

It is produced in sheet form for safety-glass, aircraft and decorative industries and is available in Great Britain in the following sizes: 55 × 24 in. and 50 × 16 in. and from 100 to about $\frac{1}{2}$ in. thick. Rods can be supplied in 52-in. lengths and $2\frac{1}{4}$ -in. diameter.

In addition to the sheet form, moulding powders have become available in the last ten years and have been employed in ever-increasing quantities with the introduction of the new technique of injection moulding. All forms are available in transparent, translucent or opaque colours.

Regenerated Cellulose—Viscose.

This is not normally considered a plastic since by far the greatest proportion goes to the textile industry as the fibre rayon.

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But enough quantities of film as well as bottle caps are made from viscose to warrant its inclusion here.

Manufacture.—Viscose differs from cellulose nitrate and acetate by the fact that the finished product is not a combination with another chemical compound (e.g. nitric acid or acetic) but remains cellulose. The change is the loss of the original fibrous structure without any great change in the molecule.

The raw material is cellulose—generally wood pulp or paper. Treatment with caustic soda followed by carbon bisulphide and then again with soda results in the production of a viscous liquid. For the production of rayon the fluid is squeezed through a spinneret, a metal disc containing numerous tiny holes, and the extruded fine fibre hardened in an acid bath.

Viscose film (it is best known on the market under the trade name of "Cellophane") is produced by spreading viscose dope on rollers.

Casein.

One of the oldest plastics in industry is casein, which is derived from milk. It is one of the protein plastics and, although of little or no application in the heavy industry, it enjoys great popularity in the fancy-goods trade, where its cheapness and the beauty of its finished texture make it attractive. The finished sheet or rod is known as imitation horn and can be made to resemble tortoiseshell very closely.

Manufacture.—The earliest developments took place probably about the year 1897 by a German chemist, named Spitteler, working for a firm desirous of producing a material for making white boards for school work. Skimmed milk is treated with rennet and the precipitated casein is washed and dried, the pure casein resembling a granulated powder. In order to make a plastic material from this, it is mixed with a little water to swell it, pigments, dyestuffs and certain softening or plasticising chemicals. The resulting mixture is not a paste, but a damp powder. This powder is then expressed through a high-pressure extruding machine to form solid rods or, alternatively, through the machine fitted with a mandrel if tubes are required. Sheets are made by packing a number of rods together between two sheets of metal and subjecting them to pressure in a "daylight" press. Rods, sheets and tubes are then placed for prolonged periods in

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tanks containing formaldehyde solution in order to harden and stabilise them.

Properties and Uses.

Tensile strength	7,000-8,000 lb. per sq. in.
Water absorption	5-7 per cent. by weight in twenty-four hours' immersion.

Casein plastics are quite strong, but the great drawback is their high water absorption, thus limiting their applications. Even so, some small use is made of them in electrical work for low-tension parts.

By far the greatest quantities are employed in the fancy goods trade. It may be pointed out here that the casein-working trade does not use moulding plant. Its raw materials are the rods, tubes and sheet described above, which it fashions by sawing, drilling, turning, grinding and polishing, to which processes the raw material readily lends itself. Fountain pens, "tortoiseshell" objects, ladies' buttons, umbrella handles, combs, knitting needles and dress buckles are thus produced. (Men's buttons, on the contrary, are made from corozo or ivory nut, a much cheaper raw material.)

Bitumen.

Bitumen, asphalt, pitches and similar materials form a small yet important branch of the plastics industry, being employed in the electrical industry where cheapness, backed by reasonably good dielectric strength, is important. The important point to realise about these compositions is that not only are they thermoplastic, but they are actually moulded in cold moulds. They were originally conceived to provide a material for electrical construction as an addition to ebonite, mica and porcelain, and although the electrical properties are well below these, yet they serve admirably for many purposes.

The composition is generally made up by melting bitumen and mixing with asbestos and silica dust. The hot mixture resembles dough or putty and while in this condition is placed in a cold mould, when it is pressed into the desired shape. On cooling the moulded shape is hard and reasonably strong. Terminal blocks, panels, transmission parts, and overhead line insulators are widely produced for the electrical industry, and battery

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boxes and accumulator cases for the motor-car industry : bitumen mouldings are very resistant to sulphuric acid :

Tensile strength	about 1,100 lb. per sq. in.
Cross break strength	3,000 " " " "

Polymerised Thermo-Plastics.

All the previously discussed thermo-plastics are derived directly from natural materials, cotton, wood, bitumen, milk, etc. They were all known and used prior to 1914, some of them being well established, as we have already indicated, for over forty and sixty years.

Within the last ten to fifteen years there has been added to this section of the industry a large number of synthetic compounds, that is, substances built up by purely chemical means from very simple chemicals. They have assumed great importance to the plastics industry, because of their manifold advantages over the older type.

At this point it will be interesting to indicate some of the important differences between celluloid or cellulose acetate and these new synthetic thermo-plastics.

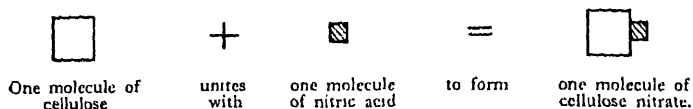
In the manufacture of celluloid or cellulose acetate we begin with the large, heavy and complicated molecule of cellulose and we obtain a union between this and a very small nitric acid or acetic acid molecule. The new celluloid or acetate molecule is only very slightly larger in weight or size than the original cellulose molecule. It has changed slightly in chemical character, so that we are now able to dissolve the new cellulose form in special solvents, in which cotton would not dissolve, to make a plastic.

With the new thermo-plastics we are about to describe we begin with a very simple organic substance of small molecular size and weight. By special processes we are able to make a large number of these small similar molecules join or coalesce to form one very large molecule. By such a method from a simple liquid we can make a solid. This process is called polymerisation and the resulting product is called a polymer.

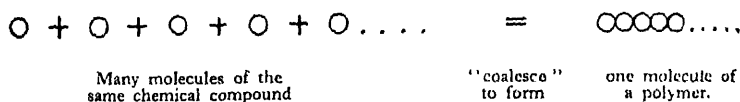
We may portray the difference in production between, say, celluloid (cellulose nitrate) and any polymer by the following diagrams. (They are, of course, neither chemically nor physically correct, but merely serve to indicate the difference in the type of reaction.)

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Cellulose Nitrate :



Polymer :



In actual practice many hundreds of small molecules may be made to form one molecule of a polymer.

The following new plastics are among the polymers :

Polystyrene.

To make this we begin with a simple well-known liquid called styrene, made from benzene. Styrene is a colourless, odorous liquid boiling at 150° C., but on heating under carefully controlled conditions it polymerises and changes to the solid polymer, called polystyrene. It is probable that in this change several hundreds, or even thousands of molecules of the original liquid styrene coalesce to form one molecule of the new solid polystyrene.

Properties.—Polystyrene comes on the market as a snow-white powder, which in the mould is compressed to form a transparent substance outwardly resembling cellulose acetate. It possesses, however, certain properties which render it an outstanding plastic in many fields :

Specific gravity	1.05
Tensile strength	2½-3 tons per sq. in.
Compression strength	7 " " " "
Impact strength	0.2
Power factor	0.0001
Breakdown voltage (50 cycles)	500-700 volts per mil.
Water absorption (24 hours)	nil

Its impact strength is somewhat less than cellulose acetate, that is, it is more brittle, but its great resistance to water and its excellent electrical properties make it an admirable material for high-frequency television equipment and transmission cables.

In Britain it has been almost solely used for electrical purposes,



Crude methyl methacrylate polymer ready for drying process

(Courtesy : E. T. Du Pont de Nemours.)

Facing p. 13.]

THERMO-PLASTIC AND THERMO-SETTING RESINS

but in Germany it replaces cellulose acetate in many applications, since cellulose plastics are not made from indigenous materials. Thus boxes, bottle caps, toys, etc., of polystyrene are quite common in Germany. Although a high-priced material, its low specific gravity and suitability for high-speed production lower final costs considerably.

“Acrylic” Resin.

When about the year 1935 this new type of resin first appeared on the market, it was received with acclaim because of its amazing optical properties and, consequently, because of its great possibilities in fields that could not be entered by any other plastics. Indeed, optically, it is clearer than glass and it also possesses the strange property of being able to transmit light through its curved forms. It thus assumed a great importance as an organic “glass.”

Manufacture. The best known of the “acrylic” resins is chemically described as poly-methylmethacrylate—a derivative of acrylic acid. The raw material for its manufacture is coal, from which ethylene is obtained. This gas is treated with acid to form ethylenechlorhydrin, from which is produced acrylic acid and, thence, methylmethacrylate. This liquid is then polymerised to the solid resin.

Properties.

Specific gravity	about 1.2
Water absorption (7 days)	0.25
Tensile strength (lb. per sq. in.)	10,000 lb.
Dielectric strength (volts per mil.)	300

This polymer is produced as cast sheet or cast rod, or in a powder form suitable for moulding by compression or injection moulding.

The sheet, in which form the resin is most widely used, can be manipulated in exactly the same manner as cellulose acetate sheet: that is, by warming to about 100° C. it can be formed to desirable shapes, its largest outlet being the making of transparent gun-turrets, windscreens, etc., for aircraft. For these purposes the resin is extremely valuable because of its stability at very low temperature.

One of the most important outlets for this material which

PLASTICS IN INDUSTRY

first attracted industrialists is the optical industry. We refer to this work in a more appropriate chapter.

"Acrylic" resin, too, lends itself admirably to manipulation by the artist, for not only can beautiful effects be obtained from it by turning and surface grinding, but its forming properties in rod, tube or sheet enable it to be made into lovely transparent shapes. Artists in the United States especially, have rapidly adopted it for producing furniture.

A word should be added here regarding the moulding powder variety. This is not, in fact, a powder, but a form made up of very tiny perfectly spherical shapes of the order of $\frac{1}{100}$ in. in diameter. It is probable that some use will be made of this, as such, by a spraying process, depositing the spheres on a suitably receptive surface to make a special type of reflector. In Great Britain the powder is widely used for moulding special units such as telephone receivers, because of the low water absorption of the finished moulding, good electrical properties, its beauty and good strength.

POLYVINYL CHLORIDE AND POLYVINYL ACETATE RESINS

The last four or five years have seen the phenomenal growth of these compounds, which are made with acetylene or natural gas or "cracked" petroleum gases as a starting-point, converted into vinyl chloride and vinyl acetate, both of which are liquids, and then by polymerisation changed to solid plastics.

Much of the earlier work was carried out in Canada and U.S.A. (principally on polyvinyl acetate) and in Germany and Great Britain (principally on polyvinyl chlorides), and although large quantities of the separate plastics are made and employed, mixtures of both are becoming of widespread importance. These mixtures are not mechanical mixtures of the separate polyvinyl acetate and polyvinyl chloride. The liquid vinyl acetate and chloride are first mixed together and then polymerised.

There is a considerable range of these plastics depending on the extent of the polymerisation, which varies from the coalescence of about 75 to 250 molecules to form one molecule of the solid. The lower the polymerisation the softer and more rubber-like the plastic; the higher the polymerisation the harder and stiffer the final polymer.

Thus some of these remarkable plastics are of rubber or

THERMO-PLASTIC AND THERMO-SETTING RESINS

linoleum texture, while others are harder than a very hard wood :

Specific gravity . . .	about 1.35
Tensile strength . . .	4-5 tons per sq. in.
Impact strength . . .	up to 0.6
Water absorption . . .	0.1 (twenty-four hours' immersion)
Breakdown voltage (60 cycles)	650 volts per mil.

Their resistance to chemical action, including oxidation, low water absorption, toughness, excellent electrical properties and range of flexibility made a great appeal to the electrical industry, where their use as cable-sheathing is now widespread. One U.S.A. concern states that between 1937 and 1939 it has produced 50,000,000 yards of such cable.

More recently polyvinyl plastics have been employed as floor-cloth, long-playing phonograph records, tubes for conveying water and beer, etc., storage batteries, and as covering for cloth.

They are available in sheet, tube and moulding powder form.

Polybutylenes.

In this section must be mentioned an interesting series of thermo-plastics which resemble the polyvinyls closely. The polybutylenes, made from a gas called isobutylene which is extracted from "cracked" petroleum gases, have been produced in Germany and the U.S.A. One of this type on the market is sold in the form of foil and is extremely stable to acids and alkalis. It has been suggested for the lining of acid storage tanks, for making wooden containers water-tight and as an intermediate layer to prevent the passage of water through brickwork. Furthermore, it has been advocated for roof joints and the lining of guttering. Polybutylenes are also available in paste form and so employed by German railways to impregnate wagon sheets, thus replacing linseed oil. It is also stated that these compounds are exceptionally resistant to mustard gas.

POLYETHYLENE

This is one of the newest polymers and, although no exact information is available, seems to be confined in manufacture to Great Britain.

It appears to be one of the simplest of all polymers, since it is

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made from the direct polymerisation of the very simple gas ethylene obtained from coal. Again a wide range is possible. In texture they resemble the polyvinyl plastics, and it is even claimed by some that they possess even better electrical properties.

Sheet, tubes and tape forms are available and, in addition to electrical applications, one form is admirably suited for the making of bottle closures, since they can be made not only colourful but are easily moulded and, what is very important, do not need a liner. They are self-sealing on the bottle rim.

NYLON

The most recent and perhaps promising plastic so far discovered has just appeared (1940) as a marketable product.

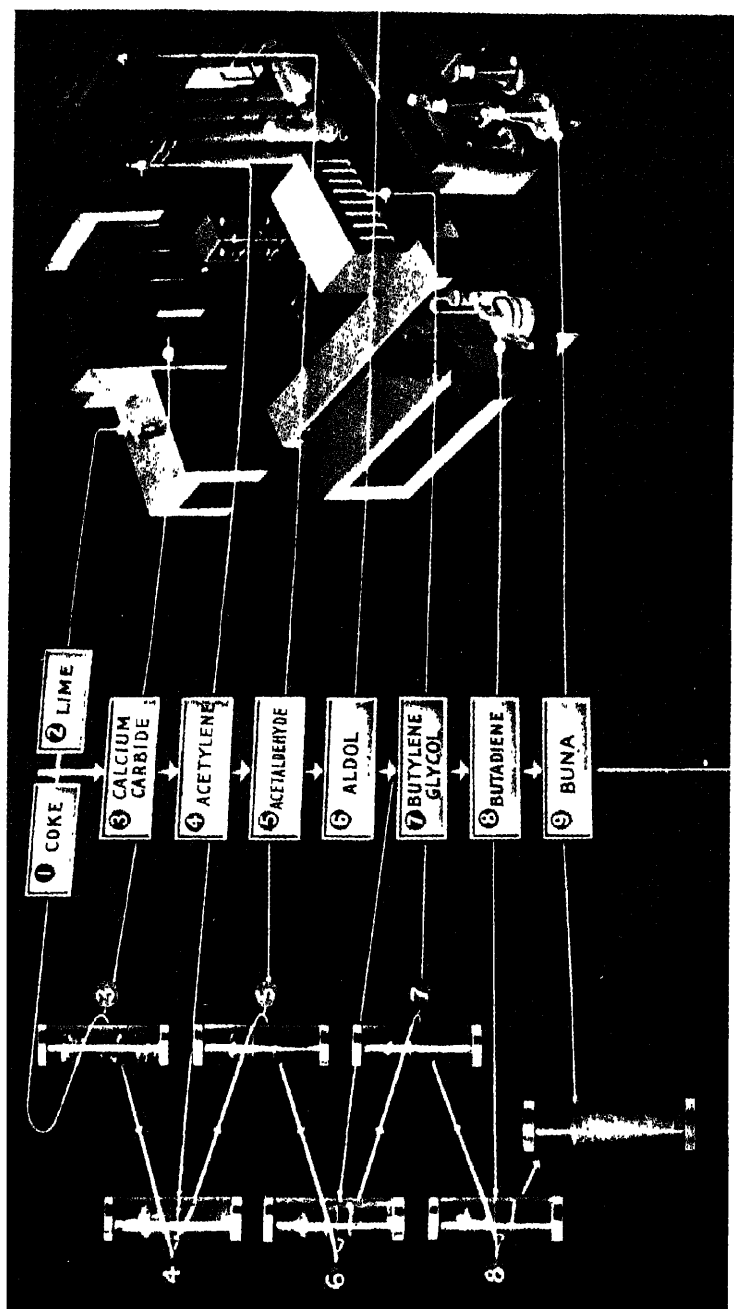
It had long been prognosticated that the strongest plastic would be of a polymerised protein nature. How true this is for nylon is not quite clear, but it appears to be much stronger than any other yet made.

The industrial research on this material has been carried out by E.I. du Pont de Nemours Inc. of U.S.A. and seems to have followed the classical work of Emil Fischer of Germany, who attempted to produce proteins from simple amino-acids. By reacting certain organic acids with amino compounds and then polymerising the products the chemists of du Pont's have succeeded in making a series of plastics now termed nylon.

In one form nylon is produced as a thread admirably suited, because of its strength, for the production of stockings equal to the best silk stockings, fishing lines, and even tooth-brush bristles. Tooth-brush bristles have now made their appearance in England, where manufacture of nylon is being carried out. They are stated to be much more resistant to rubbing than the natural bristle and each bristle is perfect in form and colour when it is extended. The elaborate processes of picking, cleaning, and disinfection are avoided.

SYNTHETIC RUBBERS

The name "synthetic rubber" should rightly be applied only to those synthetic materials whose molecules resemble very closely those of natural rubber. There are a number of these, but in addition there are also some synthetic compounds whose molecules differ materially from the natural rubber molecule, but which are



synthesis of Buna synthetic rubber (Paris Exhibition 1927)

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2. Resin impregnation of paper or fabric—laminated material.
3. Castings for further working by lathe, drilling, grinding, etc.
4. Solutions in drying oils for the paint and varnish industry. This section is outside the scope of this book.

Moulding Powders.—For moulding operations the pure first-stage resin is never used alone, but is ground, mixed with fillers to a plastic condition and, when cooled, re-ground to a fine mesh. By varying the type of filler (which may be as much as 50 per cent. of the finished powder) different properties are conferred on the finished moulding. Thus, wood flour, asbestos, mica, cotton flock and other fabrics, in addition to pigments, are employed.

Wood flour is employed for what are called "General Purpose" moulding powders; these give very satisfactory results for many purposes and are the cheapest type. The other fillers are used to give increased heat resistance, exceptionally high electrical properties, great strength, especially impact strength, moisture or acid or alkali resistance, and so on. The properties of some of the mouldings made from different mixtures are given in the chapter entitled "Specifications."

There are literally dozens of different phenolic powders made by each of the great manufacturing concerns to suit the demands of the different buying industries. What is most important is that the scientific control of the manufacture has happily reached such a high pitch that consistent quality as to both physical and chemical properties is general. This is reflected in the fact that these powders are by far the widest used of all plastics and the use is growing at a rapid rate.

Cast Phenolic Resins.

In addition to the foregoing methods of transforming the half-stage liquid resin into moulding powders, etc., one of the most interesting is the production of transparent solid forms by the very simple process of casting it without fillers.

Manufacture.—The phenolic synthetic resin employed for casting is not produced in exactly the same way as that described for resin for moulding powder manufacture. During the produc-

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tion of the latter, water separates from the resin and is removed by vacuum. The latest methods adopted for cast resin manufacture result in resin that still contains a small proportion of water. But the size of the particles of this contained water can be so regulated that the final cured resin can be made either perfectly transparent, because of extremely small particles of water, or perfectly opaque when the particles are larger. Intermediate-sized particles provide translucency. The addition of colours produce lovely effects.

Casting.—The hot half-stage resin in syrupy form is poured into lead, glass, or rubber moulds, which are placed in heated ovens maintained at 75° – 80° C. for considerable periods. Forty-eight hours or more are generally required to transform the half-stage soluble resin to its final infusible, insoluble form.

The chief advantage in casting resins is the fact that lead, glass, or rubber moulds are simply and cheaply constructed, and where lead moulds are employed they can be re-melted and the lead re-used. In the moulding of resin powders, extremely accurately machined and costly moulds of special steels are necessary. Thus, for the production of a cast resin rod a simple lead tube closed at one end is made. This rod, when finally hardened, is removed from the mould and on slicing, drilling, otherwise machined, and finally polished, can be made into buttons, imitation jewellery, shaving-brush handles, etc. Similarly, using slightly more complicated moulds, tubes and rods of various cross-section or profile, box-shapes, blocks, sheets, and even two-colour castings can be secured to make toys, table-napkin rings, letterings for display purposes, and radio cabinets.

The most sensational mouldings of cast resin were seen at the New York Fair in 1939, where there were displayed a number of more than life-size transparent figures illuminated from within. These were each about 10 ft. in height and weighed $\frac{3}{4}$ ton. Made in glass they would have weighed some $1\frac{1}{2}$ tons. In spite of their glass-like appearance, the castings are extremely strong.

Properties.

Specific gravity	.	.	.	.	1.27
Tensile strength	.	.	.	.	3–4 tons per sq. in.
Cross break strength	.	.	.	.	5–8 „ „ „ „

More recently cast resins have been produced in Germany by

PLASTICS IN INDUSTRY

Dr. Raschig that are considerably stronger, and in view of the simplicity of producing structures, are now employed in chemical engineering as acid-resisting tubes for conveying acids, acid-pump housings, etc.

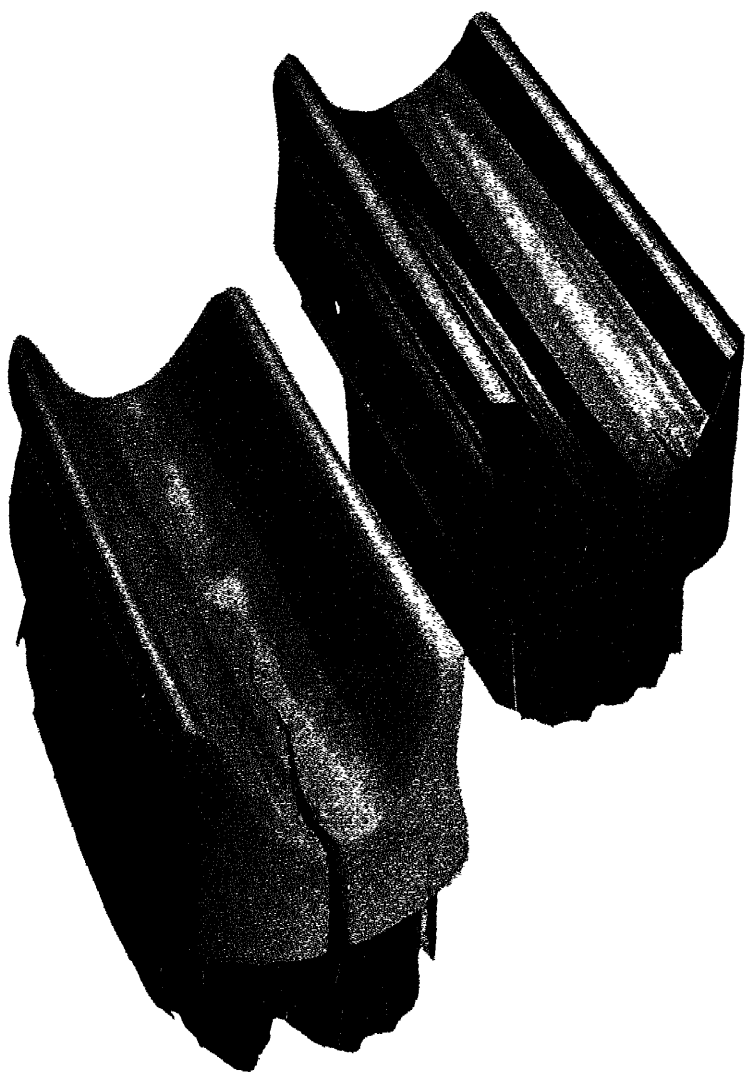
Some indication of the durability of cast resins may be gathered from the following simple, but practical, tests carried out on two nail-brushes. The accompanying photograph shows them in actual size. That on the left is a brilliant red-coloured brush that has been in more or less continuous use for two years and nine months. Twice a day after use it was allowed to stand in very hot water (150° F.) for two minutes. After about twenty-one months a fine crack appeared, which has expanded to its present dimensions. The brilliant polish has diminished, but the colour is as vivid as ever. A slight blister has appeared in the centre of the groove. Nevertheless, the brush is still being used and appears "as good as ever" and, although the crack indicates serious weakening, is still very strong. Moreover, probably because of the brilliant red of the resin, the crack is not as visible as the black and white photograph seems to indicate.

As for the black brush shown on the right, this has had a less strenuous test. It has been in continuous use for fourteen months for ordinary nail-scrubbing purposes, but has not been immersed in very hot water afterwards. Outwardly there appears to have been no change whatsoever. No cracks have appeared, nor has the brilliant lustre of the resin diminished.

These tests speak well for this "luxury" trade resin, especially, also, since both brushes have been dropped a goodly number of times, due to careless handling. Moreover, it should be noted that since 1937, when both were bought, improvements in quality have been made in the manufacture of cast resin.

Resin Impregnation of Paper, Fabric and Wood.

The impregnation of relatively large sheets of paper and other absorbent materials with resin, by using alcoholic solutions of resins in the first stage, has introduced a new raw material for a type of fabrication which is not possible by the moulding of powders. Since paper coating has long been known, continuous rolls of paper, say 6 ft. wide, can readily be impregnated with resin. It can therefore be readily realised that by consolidating under heat and pressure, a large number of these single sheets, a



Two cast-resin nail-brushes which have undergone severe and prolonged tests.
(See p. 22.)

[Facing p. 22.]

THERMO-PLASTIC AND THERMO-SETTING RESINS

thick and large sheet or block of solid construction is formed. The value of such structures of great strength, high dielectric properties or, alternatively, æsthetic appearance, is obvious.

Production.—The impregnating or dipping plant consists of huge machines which are, in effect, conveyor rollers. At one end a large roll of paper, some 6 ft. wide, rotates, carrying the paper sheet forward and down into a shallow tank running the width of the paper and containing a solution of the synthetic resin in alcohol. From this tank the paper, now wet and saturated with the solution, enters a long enclosed chamber, often 100 ft. or so long, through which hot and conditioned air is passed to remove the solvent, leaving the pure resin impregnated in the paper. By the time the paper leaves this heated chamber it is perfectly dry and is rolled on rollers at the other end of the plant. The paper now has the appearance of a translucent shiny sheet with a hard surface.

Consolidation of Impregnated Paper—Laminated Sheet.

—The impregnated sheets are then cut into sizes suitable to the presses available. For the production of wall veneers or for electrical “boards,” for example, sizes up to 6 × 3 ft. or 8 × 4 ft. are common.

A number of such sheets then, according to the thickness of the compressed “board” required, are placed one on top of another, placed between two highly polished metal sheets and compressed between the heated flat platens of a hydraulic press. The press may contain as many as a dozen platens, so that that number of laminated boards can be produced at the same time. The platens are heated by steam, giving a temperature of about 170° C. and a pressure of $\frac{1}{2}$ ton to 1 ton per sq. in. is exerted on the sheet. The resin is thus heat-hardened to its final infusible condition. Sheets 1 in. thick and over can be made. Insulators of many types can be produced by sawing, drilling or otherwise machining thin or thick sheet. For the production of insulator tubing the impregnated sheet as produced on the dipping and drying machines is wound on to rollers and then cured on heated mandrils.

There is little difference between the manufacture of insulator sheeting and of wall and door veneers or table tops. Since the latter are utilised because of their decorative purposes, in addition to their resistance to water or alcoholic beverages, the top sheet

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is coloured and decorated by a printed design. Many beautiful effects are thus obtained. Since laminated material is so readily worked by saw, inlays of different colours can be incorporated in a door or a table-top.

Properties of Laminated Paper Sheet.—The laminated materials are, on the whole, stronger than those made from moulding powder :

Specific gravity . . .	1.3-1.4
Compressive strength . .	9-18 tons per sq. in.
Tensile strength . . .	4-6 " " " "
Cross break strength . .	6-14 " " " "
Impact strength . . .	0.3-3.0 ft. lb.
Breakdown voltage (60 cycles)	400-1,000

Laminated Fabrics.

The same process of impregnation and consolidation can be carried out, utilising strong cotton sheet or other fabrics instead of paper. The resulting blocks or thick sheets (thicknesses of 10 in. are quite common) are extremely strong and are utilised for the fabrication of gear wheels and heavy duty bearings. Cylindrical blocks are first cut out of the laminated sheet and teeth are then cut by machining.

Properties.—The laminated fabric material for gear fabrication normally turned out by British manufacturers shows better results than the limits given under British Standard Specification 668 (*loc. cit.*).

Average Manufactured Laminated Fabric.

Tensile strength . . .	7-7½ tons per sq. in.
Cross break strength . .	9-11½ " " " "
Ultimate crushing strength .	15-16 " " " "

Impregnation of Wood Veneers.

The impregnation of wood veneers is yet another technique that has been developed in recent years for the production of heavy insulating components and also for structures for heavy engineering. The process applied is described in the chapter devoted to engineering applications.

THERMO-PLASTIC AND THERMO-SETTING RESINS.

Resin Emulsions and High-strength Moulding Sheet.

One of the most recent methods of obtaining high strength moulding materials is that of impregnating fabrics with emulsions of phenol-formaldehyde synthetic resins in water. Little is known about the actual fabrication, since great secrecy is maintained, but it is a method of great promise and considerable success has already been achieved. The main developments appear to have taken place in U.S.A., Germany and Great Britain.

Broadly speaking, the operations are those similar to the felt-forming processes carried out in paper manufacture. Cotton flock is floated and treated with a resin emulsion so that impregnation is thorough, and orientation and felting is obtained in the trough. Excess resin emulsion and water is removed by suction below, leaving the closely felted material behind. The latter is dried and flattened into sheet which can be moulded or, alternatively, shredded into small pieces and used as a moulding powder. Moulded articles made from these are stronger than those produced from any other moulding material. Claims have been made that they possess three to five times the toughness or impact strength of objects made from ordinary high-strength moulding powders made by incorporating resin and fabric on masticating rollers.

In Great Britain the material has so far been used only for electrical parts, but in the U.S.A., where it is termed resin board, applications have been wider. Refrigerator handles capable of withstanding very high shocks have been made, and it has also been announced that one company is making sewing-machine housings of the material, while the Ford Co. has made trunk compartment covers for motor-cars. The production of motor-car doors and, in view of its heat-insulating properties, refrigerator doors, has also been suggested as likely objects of future manufacture.

Properties.

Specific gravity	.	.	.	1.35
Tensile strength	.	.	.	up to 5 tons per sq. in.
Impact strength	.	.	.	up to 12 ft.-lb. per sq. in.

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Soya-Phenol-Formaldehyde Resins.

With the object of producing a cheaper moulding powder, workers in the U.S.A. (U.S. Regional Soybean Industrial Products Laboratory, Urbana, Illinois) have been experimenting with considerable success with plastics made from the soya bean, which contains a high percentage of protein. Work on the protein itself, which was obtained after solvent extraction of oil, proved unsuccessful. The modern production of the plastic appears to be the treatment of the soya protein flakes with formaldehyde and then mixture on masticating machines with phenol-formaldehyde resins. Mouldable powders are thus made which have proved so satisfactory for some purposes that the Ford motor works in Dearborn are using them extensively for mouldings such as coil cases, accelerator pedals and even tractor seats.

UREA AND ALLIED PLASTICS

This second large section of the thermo-setting plastics was first discovered by Pollak, a Viennese chemist, in 1924 and produced commercially in England about the year 1925.

It had been realised that synthetic resins of a light-coloured type would find a market which the darker phenol-formaldehyde resins could not enter with satisfaction. The answer came by the discovery of the urea-formaldehyde type.

Manufacture.—Urea is a white organic compound in powder form manufactured by the chemical interaction of two simple common gases, carbon dioxide and ammonia. By interaction with formaldehyde a syrup is obtained containing the first-stage resin. From this the solid urea resin, fusible and water soluble, is formed.

Like the phenol-formaldehyde resin, this is employed to make :

- (a) Moulding powders, by mixture with fillers.
- (b) Solutions for the impregnation of paper, cloth and wood for consolidated laminations.

Moulding Powders.—These are prepared by mixing the powdered intermediate stage resin with wood flour or finely shredded paper, and since this mixture is of a pure white, delicate pastel shade pigments can be added to give beautifully coloured

THERMO-PLASTIC AND THERMO-SETTING RESINS

mouldings impossible of attainment with phenol-formaldehyde powders. The technique of high-pressure moulding from the powder is very similar to that carried out with the phenol-formaldehyde resins and, like these, the half-stage resin hardens under heat and pressure in the steel die to give rigid, hard, and infusible mouldings. It was with these powders that the first plastic cups and saucers were made for the picnic and nursery trades. That they are more strongly entrenched in these markets than ever speaks well for their utility and beauty. While they are not unbreakable, such mouldings, because of their lightness and strength, are very durable. Moreover, they are odourless and tasteless. Since those early days the use of these moulding powders has spread greatly, especially in the lighter industries. Translucent lamp-shades, radio cabinets, bottle-closures, buttons, cigarette-boxes, and other "fancy" containers for perfumes and powders and a host of other general applications are now commonly manufactured.

Properties.—The following data is for an average paper-filled moulding :

Specific gravity	1.45
Tensile strength	4-5 tons per sq. in.
Cross break strength	4-5 " " " "
Breakdown voltage (60 cycles) .	700
Water absorption	about 1 per cent. (twenty-four hours' immersion).

It will be seen from the above that although the water absorption is high, yet the moulded plastic possesses good electrical properties. It is also "non-tracking," and is, in consequence, in demand for special electrical components.

Impregnation of Paper, Fabric, and Wood.

Impregnation of paper and the consolidation of such sheets is carried out in a manner similar to that described when using phenol-formaldehyde resin solutions. The principal uses of such sheet are for the production of table-tops and similar decorative and utility purposes. Alternatively, the urea resin solutions may be employed as glues for making plywood and similar structures, not only for furniture manufacture, but also for certain heavy industries, such as aircraft construction. The glues make ex-

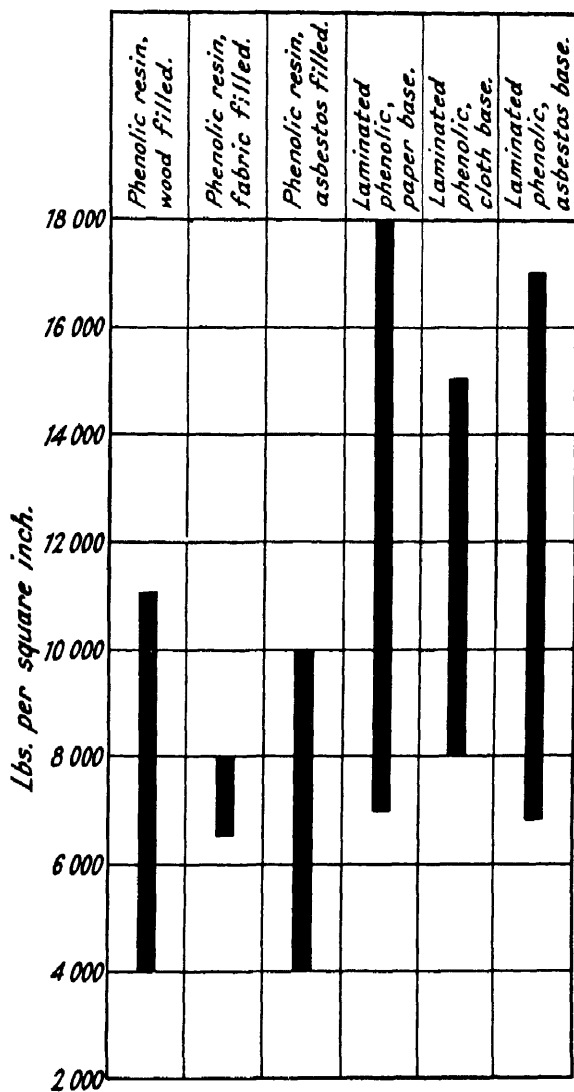
PLASTICS IN INDUSTRY

tremely strong jointings, which are unaffected by bacterial or fungus attack.

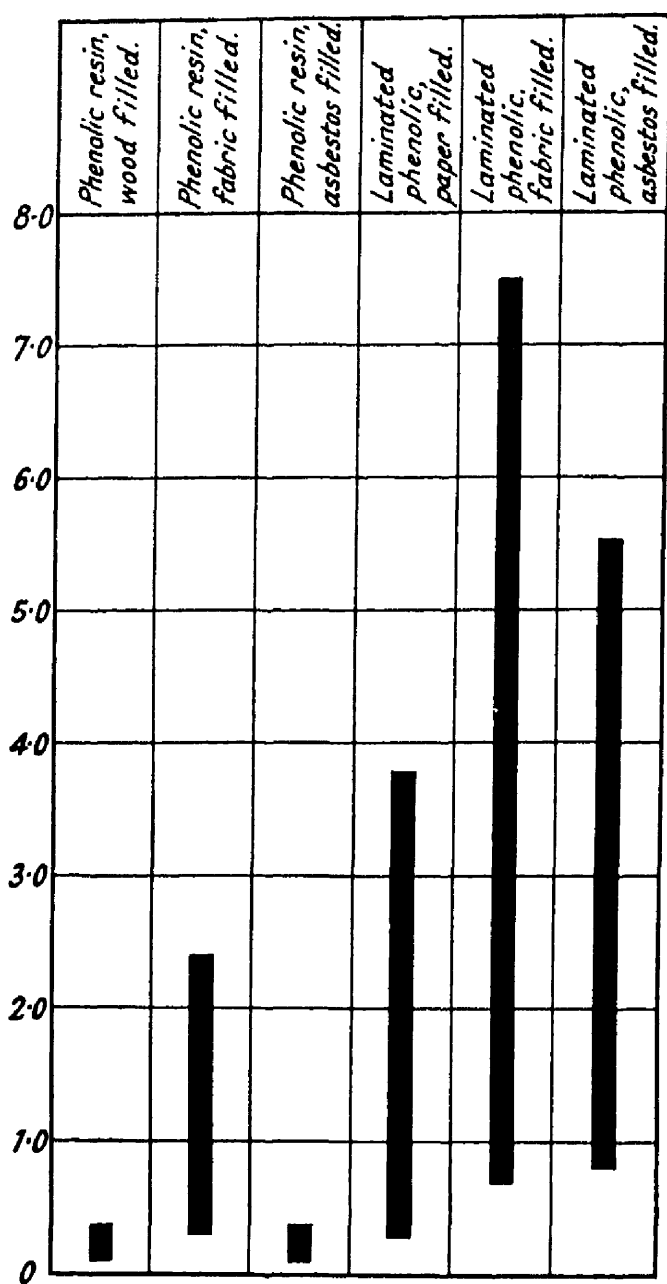
Melamine-Formaldehyde Moulding Powders.

The melamine plastics are included in this section since, like urea, melamine contains what is chemically called an " amino " (ammonia) group in the molecule. Both types are thus somewhat allied in character and appearance, and, indeed, melamine resins are employed for much the same purposes as urea resins. The advantages claimed for parts moulded of melamine resins are stability in the presence of heat and hot water and fruit juices. They produce beautifully coloured mouldings, and in some countries are usurping the position held by urea mouldings for the manufacture of cups, saucers, and other table ware. Little use of them is made in Great Britain. They are of Swiss origin.

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Tensile strengths of the best-known types of phenolic resins. The heavy black lines show the wide ranges available to the industrialist.



THERMO-PLASTIC AND THERMO-SETTING RESINS

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CHAPTER III

SPECIFICATIONS

ONE of the most powerful instruments of control in modern industry, in mass production and unit construction alike, is the official specification. It is both an arrow pointing to an ideal and a means of raising the quality of general production.

It will therefore be a disappointment to the engineer that specifications for plastics are largely lacking. This lack, on the other hand, is understandable in view of the youth of the plastic industry, because methods of test that apply to metals cannot always be applied to plastics, and consequently new ones have to be devised and, moreover, because change is very rapid. The industry, internationally and nationally speaking, is far from being organised sufficiently to permit of official specifications.

On the whole, the situation is as follows. All the great consumer companies throughout the world, especially the electrical companies, have their own specifications and have devised their own tests.

Since the most important plastics began their useful life in the electrical industry, the first specifications were necessarily built up on electrical tests only. There was little difficulty in making these, since the phenol-formaldehyde mouldings approach sufficiently near the older materials in physical properties.

On the whole, Great Britain appears to have advanced more than any other country in the matter of official specifications.

In 1929 there first appeared British Standard Specification 316, which deals with synthetic resin varnish paper boards and tubes, Grade II (low resin content), while B.S.S. 547 (1934) deals with Grade I (high resin content). The tests on these materials are almost identical—electric tests, mechanical tests, water absorption and the effect of hot oil. Grade I also undergoes

PLASTICS IN INDUSTRY

a test for surface insulation after a "tropical" conditioning test. Both specifications are widely employed by manufacturers in the electrical industry.

In 1936 B.S.S. 668 was devised to standardise Laminated Synthetic Resin Bonded Sheet (Fabric Base).

In addition to the usual mechanical, water absorption, and hot oil tests the specification includes "Tolerance on Dimensions" and machining tests. There are no electrical tests, nor has a toughness test been published yet.

Among the specifications are :

Tensile strength	.	.	.	.	not less than	8,500 lb. per sq. in.
Cross break strength	.	.	.	.	" " " "	16,000 " " "
Water absorption	.	.	.	.	not more than	0.6 per cent. (24 hrs.).

Thermo-Setting Resin Mouldings.

As the plastics moulding industry widened its scope, the need for specifications for actual mouldings from phenol-formaldehyde resin powders assumed great importance. In 1938 B.S.S. 771, referring solely to this type, appeared. It deals not only with the raw materials, but also with the finished mouldings. For the latter, simple tests, such as freedom from obvious defects, specific gravity, finish and degree of cure (controlled by acetone extraction) are specified.

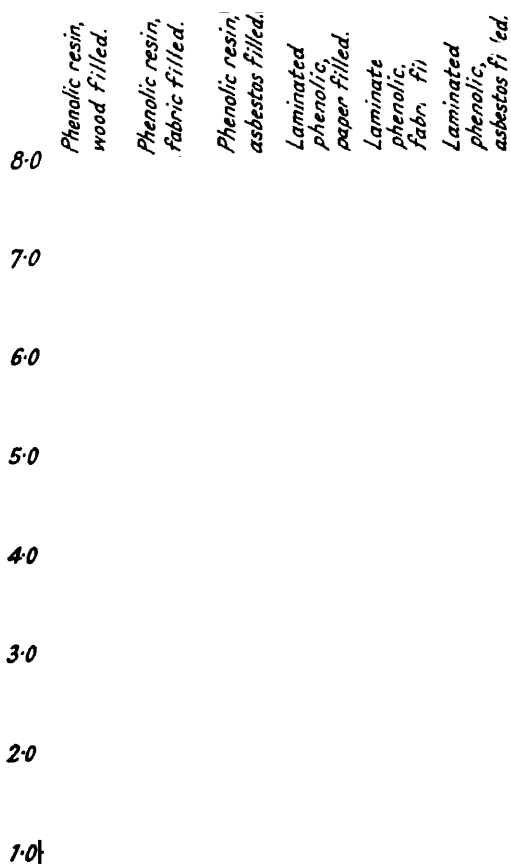
The moulding powders are classified under five headings :

G	.	.	.	.	General type.
GX	.	.	.	.	Improved type.
MS	.	.	.	.	Medium shock resistant type.
HS	.	.	.	.	High shock resistant type.
HR	.	.	.	.	Heat resistant type.

The electrical and mechanical tests carried out on these are very similar to those carried out in B.S.S. 488. In addition the heat-resistant type is tested for resistance to crushing after heating to high temperatures.

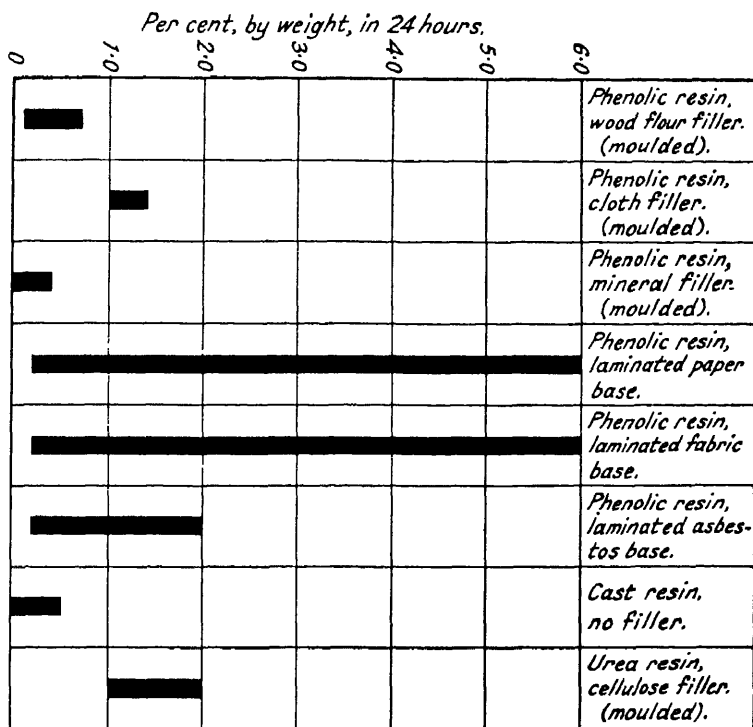
It must be pointed out that the methods of tests themselves must be carefully examined before the figures given are compared with those specified in other countries.

PLASTICS IN INDUSTRY



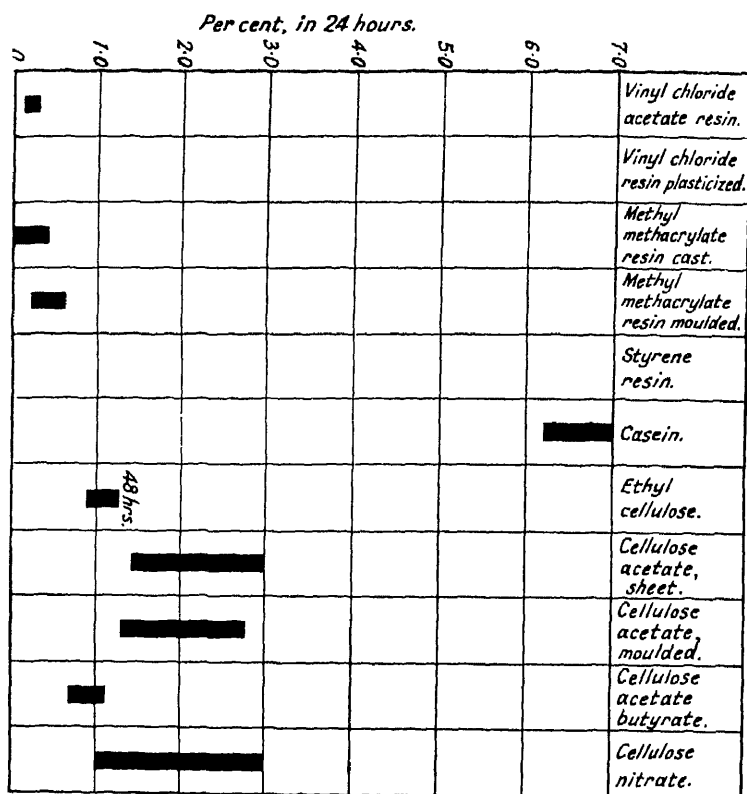
Impact strengths of the best-known types of phenolic resins, indicating their relative ability to withstand shock.

THERMO-PLASTIC AND THERMO-SETTING RESINS



Relative water-absorption of thermo-hardening plastics.

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Relative water-absorption of thermo-plastics. (Note : The figure for styrene resin is nil.)

CHAPTER III

SPECIFICATIONS

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PLASTICS IN INDUSTRY

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Among the specifications are :

Tensile strength	not less than 8,500 lb. per sq. in.
Cross break strength	" " " 16,000 " " " "
Water absorption	not more than 0.6 per cent. (24 hrs.).

Thermo-Setting Resin Mouldings.

As the plastics moulding industry widened its scope, the need for specifications for actual mouldings from phenol-formaldehyde resin powders assumed great importance. In 1938 B.S.S. 771, referring solely to this type, appeared. It deals not only with the raw materials, but also with the finished mouldings. For the latter, simple tests, such as freedom from obvious defects, specific gravity, finish and degree of cure (controlled by acetone extraction) are specified.

The moulding powders are classified under five headings :

G	General type.
GX	Improved type.
MS	Medium shock resistant type.
HS	High shock resistant type.
HR	Heat resistant type.

The electrical and mechanical tests carried out on these are very similar to those carried out in B.S.S. 488. In addition the heat-resistant type is tested for resistance to crushing after heating to high temperatures.

It must be pointed out that the methods of tests themselves must be carefully examined before the figures given are compared with those specified in other countries.

SPECIFICATIONS

As examples we can quote HS and HR materials :

	<i>HS</i>	<i>HR</i>
Ultimate tensile strength .	6,000 lb. per sq. in.	3,500 lb. per sq. in.
Impact strength (Izod) .	0.90 ft.-lb.	0.07 ft.-lb.
Water absorption . . .	350 mg.	100 mg.
Electric strength at 90° C.	20 volts per mil.	20 volts per mil.
Surface resistivity after water immersion .	100 megohms.	100 megohms.
Resistance to crushing after heating to 400° C. in bath of fusible metal		500 lb.

Plastics (London), July, 1939, published some additional notes regarding tentative and unofficial specifications of other plastic materials.

AMINO-PLASTICS

There exists at present no British Standard for amino-plastics, but two principal manufacturers are preparing the ground for a specification. They will probably follow the general lines of B.S.S. 771, but with modifications, such as thinner test pieces, the replacement of the acetone extraction test after curing by immersion in water, followed by a scratching test. It does not seem probable that any specification for amino-plastics will be introduced before the end of the present war.

Some of the proposals are as follows :

Tensile Strength.—Test piece as in B.S.S. 771, but reduced by $\frac{1}{8}$ in. all over. Standard as for GX Phenolic. 7,000 lb. per sq. in.

Impact Strength.—No agreement has been reached, but results are about the same as on a good wood-filled phenolic under the same tests.

Water Absorption.—As B.S.S. 771, but higher figure, about 350 mg., will have to be allowed.

Electric Strength and Surface Resistivity.—As B.S.S. 771. Electric strength similar to phenolics, and surface resistivity is generally better.

Flow of Moulding Material.—The cup flow method is not suitable for amino-plastics. Perhaps some type of flat disc method may be adopted.

Resistance to Electrical Tracking.—In view of the non-tracking

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properties of amino-plastics, some test for this will be included. A simple type of test is being considered, in which two metal studs inserted about $1\frac{1}{2}$ in. apart in a flat moulding are connected to a 230 volt A.C. supply choked to about 10 amps. and the circuit completed by pouring 10 per cent. salt solution on the moulding. Amino-plastics should not track, even after repeated application.

THERMO-PLASTICS

Cellulose Acetate.—This material and celluloid are so different chemically from all other thermo-plastics that it is worth while repeating in full the information regarding standards given by one of the producers in Great Britain.

There are very few British Standard Specifications for plastics made from cellulose esters. The reasons for this are threefold:

- (a) Manufacturers are in some cases unwilling to adopt specifications for materials which are still in process of development and improvement.
- (b) Cellulose ester plastics are not chemical individuals, and therefore tolerances must be allowed not only in the chemical composition of the ingredients, but also in the proportions and even the identity of the plasticisers. This opens such a wide door that a specification becomes of little use.
- (c) Cellulose ester plastics are used for a variety of purposes. A specification which would be acceptable for a plastic required for one particular purpose would usually be at fault for the same plastic if required for another purpose.

It follows from this that the service which standardisation authorities can render to the plastics industry lies more in defining the properties which are required for particular purposes than in standardising individual plastics, and it may be pointed out that the adoption of this principle gives much better opportunities to new plastics, which can then compete on equal terms with old-established plastics.

The British Standard Specifications dealing with Cellulose Ester Plastics are:

2D.50—Cellulose Acetate.

F.56—Transparent Sheets for Observation Panels.

SPECIFICATIONS

B.S.S. 2D.50. Cellulose Acetate.—This specification is for cellulose acetate base, and includes tests for stability to moisture and heat, water content, filming capacity, acidity, ash and viscosity. Methods of applying these tests are described in appendices.

This specification defines a good merchantable cellulose acetate, suitable, for example, for high-quality dope manufacture, but it cannot be regarded as guaranteeing a quality suitable for high-grade transparent sheet.

B.S.S. F.56. Transparent Sheets for Observation Panels. The title of this specification does not indicate that it applies to cellulose acetate, but the first clause runs: "1. Type of Material. The sheets shall be made from a stable variety of cellulose acetate and suitable softening or plasticising agents." The remaining clauses deal with freedom from defects, dimensions, selection of samples, transparency, freedom from brittleness, rigidity, resistance to extremes of temperature, resistance to moisture, combustibility and resistance to accelerated ageing. Not one of the tests described is specific to cellulose acetate, so that, apart from the first clause, this specification defines properties required rather than an individual plastic. It is now being revised.

There is an Air Ministry Specification D.T.D. 315 for pigmented cellulose acetate sheets which follows the general lines of B.S.S. 2D.50.

There are also various confidential Government specifications for celluloid and cellulose acetate products, the contents of which cannot be published. These have been and are still negotiated between the manufacturer and the Government departments using plastic materials.

Methyl Methacrylate.—The following relates to Diakon and Perspex, both thermo-plastics made by I.C.I. Ltd. and based on methyl methacrylate. The former is in granule form for moulding and the latter is in cast rod or sheet form. No British standards exist, but the manufacturers carry out tests to their own specifications, and in the case of Perspex sheet there is an Air Ministry specification in use, D.T.D. 339a.

(a) *Cast Sheet.*—Apart from specification of surface appearance and thickness, this sets limits for the loss of light by absorption and reflection, the tensile strength, the rate of burning, the impact strength (as measured by a ball falling on to a sheet supported in a specified manner), change in dimensions and

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transparency after soaking in water and after heating, and after exposure to arc light.

The specified limits are :

Tensile strength .	greater than 2.75 tons per sq. in., less than 4.25 tons per sq. in.
Light transmission	not less than 90 per cent. after all treatments.
Change of dimensions	not greater than 0.5 per cent. after all treatments.

The burning rate and the specified height of fall for the ball naturally vary with the thickness of the sheet but as examples the figures for a $\frac{5}{32}$ -in. thick sheet are :

Time to burn down 6 in. of 1 in. wide not less than 13 minutes. Material must not fail when 130 gram ball is dropped 2 ft. 11 in.

Material supported on steel supports at three points distant $3\frac{1}{2}$ in. from each other.

The tensile and compressive strength of Perspex vary with temperature as follows :

	<i>Ultimate Tensile Strength.</i>	<i>Proportional Limit in Compression Strength.</i>
— 60° C. . . .	6.2 tons per sq. in.	—
— 40° C. . . .	6.1 " " " "	11.0 tons per sq. in
— 20° C. . . .	5.7 " " " "	7.2 " " " "
0° C.	4.9 " " " "	5.5 " " " "
20° C.	3.7 " " " "	4.4 " " " "
40° C.	2.5 " " " "	2.1 " " " "
60° C.	1.4 " " " "	1.8 " " " "

The proportional limit instead of the ultimate strength is given in compression, since at the higher temperatures the material does not fracture under increasing loads, but merely flows.

(b) *Moulding Powders.*—Certain of the methods of test and test-pieces, specified in B.S.S. 771 for phenolic moulding powders, are applicable, but of course the moulding conditions have to be adjusted and the moulds must be cooled before ejecting the specimens. The heat resistance is conveniently measured by means of the Martens test. Typical figures for Diakon are :

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	<i>Diakon F.</i>
Specific gravity	1.19
Bulk density	0.7
Bulk factor	1.7
Water absorption (7 days)	0.24-0.30
Shrinkage on moulding	0.002-0.006
Martens point (° C.)	55-60
Tensile strength (lb. per sq. in.)	8,200-10,000
Impact strength (as B.S.S. 771)	0.30-0.35
Ultimate fibre stress in bend (lb.)	11,000-14,000
Brinell hardness	19-21
Surface resistivity (megohms)	$> 10^{10}$
Volume resistivity (megohm cm.)	$> 10^8$
Permittivity at 5×10^7 cycle	2.6
" " " 10^6 "	2.9
" " " 800 "	3.6
" " " 50 "	4.0
Power factor at 5×10^7 "	0.022
" " " 10^6 "	0.019
Power factor at 800 cycle	0.033
" " " 50 "	0.038
Dielectric strength at 20° C.	280-300
" " " 70° F.	280-300

The material retains its impact strength practically unaltered down to a temperature of -60° C.

With coloured Diakon, as with urea-formaldehyde, it is probable that a colour permanence test will be considered in drawing up any British Standards, since perfect colour stability can be obtained by choice of stable colouring materials.

Polystyrene.—Here there are no official standards at all in this country. The following figures represent the unofficial standard to which one manufacturing concern works with its own product; this material is Distrene, which is manufactured by the Distillers Co. Ltd.:

Moulding Conditions.

Compression moulding temperature	140-180° C.
" " " pressure	1,500-500 lb. per sq. in.
Compression ratio	1.93-2.05.
Mould shrinkage	about $\frac{1}{1000}$ in. to the inch
Injection moulding temperature	170-200° C.
" " " pressure	$1\frac{1}{2}$ -10 tons per sq. in.

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Physical and Mechanical Properties.

Specific gravity	1.05
Refractive index	1.62
Specific heat, cal. per ° C. per gram .	0.324
Thermal expansion, 10^{-5} per ° C. . .	7.2 (— 10° to 45°)
Softening point, Martens	87° C.
Distortion temperature (A.S.T.M. D48-37)	80-90° C.
Thermal conductivity	10^{-4} cal. per sec. per sq. cm. per 1° C. per cm., 1.9
Tensile strength	2.7-3.0 tons per sq. in.
Elongation	0.5-1 per cent.
Modulus of elasticity (lb. per sq. in. $\times 10^5$)	5.5
Compression strength (tons per sq. in.)	7 tons
Flexural strength (tons per sq. in.) .	3-3½ tons
Impact strength :	
Izod, notched bar (ft. lb. 25° C.) .	0.25-0.3
,, ,, ,, (ft. lb. — 70° C.) .	0.25 to 0.3
Brinell no. (2.5 mm. ball, 25 kg. load)	20-30
Rockwell hardness no. (½-in. ball, 60- kg. load)	90-97
Rockwell superficial hardness (¼-in. ball, 15-kg. load)	15 \times 90
Light transmission through 0.1-in. plate	90 per cent.
Water absorption in 48 hrs.	nil
Effect of ultra-violet radiation . . .	yellowes slightly
Effect of dilute acids.	none
Effect of alkalis	none
Effect of H ₂ O ₂ 100 vol.	none

Electrical Properties.

<i>Frequencies.</i>	<i>S.I.C.</i>	<i>Loss Factor</i>
50	2.2	0.0002
1,000	2.2	0.0005
200,000	2.1	0.00044
650,000	2.1	0.0002
1,000,000	2.3	0.0002
40,000,000	2.3	0.0001
Breakdown voltage, 50 cycles, volts per mil. .		500-700
Volume resistivity, ohm-cm.		> 10^{17}
Surface resistivity, ohms		> 10^{16}

SPECIFICATIONS

Vinyl Plastics.—Here again there are no specifications and the only data available to us are certain physical and chemical constants for the Gelvas, Alvars, and Formvars imported into Great Britain by Shawinigan Ltd. These are derived from vinyl acetate.

Gelvas.

Dielectric strength	1,000 volts per mil.
Dielectric constant (30° C.)	2·7
Coefficient of linear expansion	0·000086
Water absorption (A.S.T.M.)	2·0

There are seven gelvas manufactured, varying in softening point from 65–196° C. The harder Gelvas have a tensile strength of 5,000 lb. per sq. in.

Alvars.—These plastics resemble closely the Gelvas in electrical properties and water absorption. Five are manufactured, varying in softening point from 120° C. to 180° C. The Alvar with 170° C. softening has a tensile strength of 7,500 lb. per sq. in.

Formvars.

Dielectric strength	1,000 volts per mil.
„ constant (30° C.)	3·7
Tensile strength	14,600 lb. per sq. in.
Water absorption	1·3
Softening points (2 varieties)	190° C. +, and 250° C. +

The Formvars find application for moulding powders, sheets, rods and tubes, and for the manufacture of safety glass.

SUMMARY

The foregoing are almost the only specifications in existence in Great Britain. Those that are not the official issues of The British Standards Institute are the normal specifications utilised by manufacturers of the raw moulding powders and other plastics themselves, just as any chemical manufacturer must employ to control his output or to advise his customers. As indicated already, all big electric or other plastic consumers possess their own specifications—many of course in Great Britain, as in the U.S.A., France, Germany, etc., mould for their own consumption. This method is also applicable to Government Departments.

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Such specifications generally follow the standard specifications, but, for obvious reasons, differ on occasion. For example, the British Air Ministry ask the moulder who is quoting for a tender for a thick moulded plate which is cut up into specimens for testing and these latter may be cut out from the very centre of the plate. Some criticism has been levelled against this method as being too stringent, but this may be countered by the obvious retort that stringency must be expected in dealing with aeroplane parts.

There is, in fact, a criticism regarding the specifications in general, namely, that they are tests of moulding rather than of tests on the moulding powder. It has been said that it is unfair to expect powder manufacturers to mould as well as expert moulding manufacturers and, moreover, that more exact conditions of moulding should be defined. There are many tricks in the trade which influence the final properties of the moulded object. So much, too, depends on the type of press available.

The experience of the General Post Office, however, is interesting. When a powder is submitted in order that it may be placed on the Approved List, the G.P.O. state that specimens submitted may be moulded by the manufacturer or any moulder he chooses, although in general, the powder manufacturer will wish to make them himself for purposes of control and convenience. When the powder is placed on the Approved List the moulder who wishes to supply finished goods made from it must convince the G.P.O. that he can produce satisfactory mouldings. There is thus a double check. An official of the G.P.O. states that the moulding produced by the powder manufacturer is, on occasion, better than that produced by the moulding concern.

Whilst on the subject of the G.P.O., it is worth while noting some of the tests they carry out. Generally they follow B.S.S. 771, but for special objects special tests are made. Thus for the guard and plunger of the modern telephone an additional impact strength test is made on the whole piece, and is reported as such and not calculated on unit area. The blow on the guard, for example, is given at right angles to the horn at one spot. For cellulose acetate results of 2-4 ft. lb. are obtained. It is now generally known, perhaps, that cellulose acetate is used for the black G.P.O. guards and "acrylic" resins for the coloured ones.

SPECIFICATIONS

Colour fading tests are carried out, now that coloured telephones are widely used. The mercury lamp, which was originally used for the test, has proved useless because of its narrow band of light and has given place to the carbon arc.

A new telephone apparatus, the Swedish type, is now being issued, but the method of testing has not yet been decided upon. It is not known yet where the main strains will occur.

CHAPTER IV

MOULDING AND FABRICATION TECHNIQUE

HERE, again, it is not proposed to describe in great technical detail the methods by which plastics are fabricated into their finished forms. Such notes as are given here are intended merely for the better understanding of the plastics industry as a whole. They serve, too, to amplify the data already given on the physical properties of plastics.

All the fabricating operations carried out on plastics can, of course, be considered as moulding, but in practice the nomenclature of the processes adopted is as follows :

1. Blowing or shaping of thermo-plastic sheet.
2. Extrusion through nozzles or dies. This process applies to both thermo-plastic and thermo-setting plastics.
3. Compression moulding. This is the most general method adopted in fabricating from thermo-setting moulding powders. It is rarely adopted for thermo-plastic powders.
4. Injection moulding. Almost solely used for moulding thermo-plastics. Injection of thermo-setting resins has been examined, but success is, so far, limited.

The above four methods are carried out by the plastics moulding industry—a purely engineering industry. This makes use of sheet, powders, etc., which it buys from the raw materials or chemical manufacturers. While it is true that some raw material manufacturers also mould finished objects and some moulding concerns make their own synthetic resins for “ political ” reasons, this practice is very rare. It is not necessary, therefore, to include “ Casting ” in this section, since castings are made by the synthetic resin manufacturers and are sold to those concerns fabricating objects therefrom by additional but purely machining operations. Under this section, therefore, will also be given some



The polishing of cast methyl methacrylate resin (Lucite) in the form of tubes.

(Courtesy E. I. Du Pont de Nemours.)

Facing p. 45.

MOULDING AND FABRICATION TECHNIQUE

notes regarding some of the machining operations that can be carried out on these and other plastics, such as laminated material.

Blowing and Shaping Thermo-Plastics from Sheet, Rod, etc.—Most of the processes for the working of these plastics are derived from the early methods adopted by the celluloid industry. Excellent examples of combs and other shaped pieces made from celluloid about the year 1855 can be seen in the Science Museum in London, and many of the methods of manipulation evolved during those early days are still practised. Success in this type of work depends on the individual skill of the worker, since it is nearly all hand work. Bending of thin sheet, for example, is done by placing the piece on a hot plate for a few seconds, bending to the required shape, with or without a template, and then plunging into cold water. Rods may be bent by placing them in hot sand.

Blowing.—Many hollow fancy goods and toys are produced in celluloid or acetate by this process, in which two metal dies in a press are employed. In principle, two heated sheets of the plastic are held between steam-heated upper and lower dies and by the injection of air between the sheets are moulded into the dies. The sides of the sheets coalesce under the heat, forming a hollow shape, and the dies are cooled with cold water. On opening the press the moulding is removed.

Shaping of Large Plastic Sheet.—While, fundamentally, there is no difference between this process and simple bending of thin small-sized sheets, it is described, because of recent years the application in industry of very large sheets of thickness $\frac{1}{4}$ in. and even over has grown very rapidly. Enormous quantities of "organic glass," that is, cellulose acetate, and "acrylic" resin sheets are required for the windows and gun-turrets of aircraft, while the use of opaque acetate sheet is steadily increasing for ventilator ducts, ammunition chutes, etc., in the same industry.

Increase of size and increasing complexity in design has, however, necessitated the introduction of special plant. The heating of sheets of 1 sq. yd. surface obviously calls for large ovens thermostatically controlled, and the shaping of them has brought into use special moulds and jigs to hold the sheet in place while it is being cooled. The production of moulds and jigs, which are usually of hard wood, are often excellent examples of the engineer's skill, especially when it is realised that double curvatures in the

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plastic are often required, that high-dimensional accuracy is necessary and that no uneven strain on the sheet during forming must be exerted.

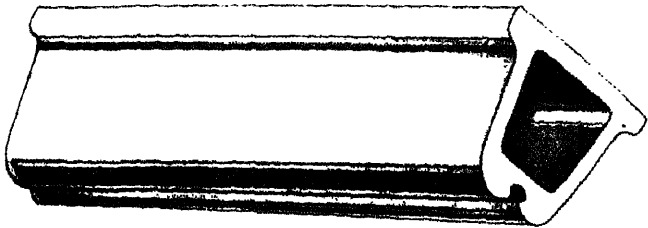
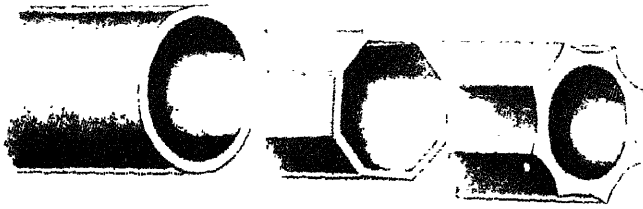
The sheet of plastic is heated in an electric oven maintained at about 120° C. Usually the sheet is hung up by means of clips, one clip being used to hang the sheet on a strong wire: another clip allows for removal of the sheet when it is soft and workable. When this state is reached it is quickly removed from the oven by the operator, who draws it firmly over the mould, using the two clips to secure a grip. The jig is then closed and the plastic sheet kept stretched over the mould until it is cold and rigid.

Trimming to design or removing waste may be carried on while the sheet is soft by means of shears, or, alternatively, when cold by sawing. These plastics have no grain: they lend themselves admirably to most types of machining, such as bevelling, drilling, turning, etc. Jointing pieces of acetate or "acrylic" resin sheets is readily carried out with satisfaction by the use of simple organic solvents, scarf and strap joints being widely employed. The surfaces may be buffed and highly polished to a glass mirror finish, or, alternatively, matt-surfaced by spraying with organic solvent.

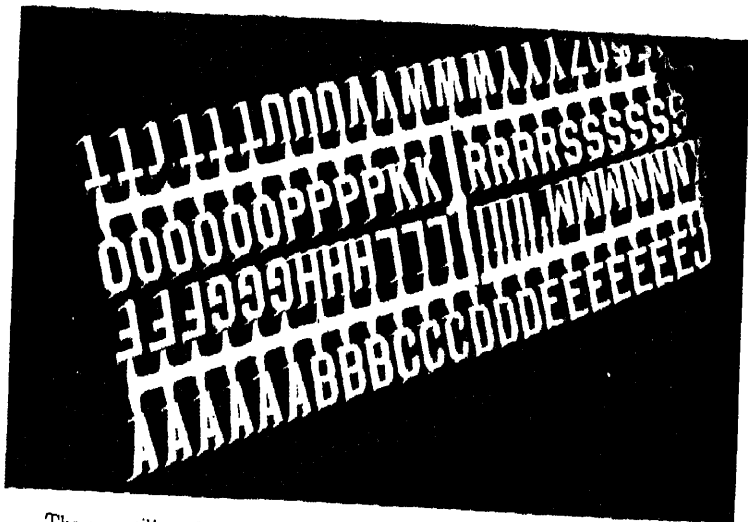
Extrusion.—This process, which originated with the production of celluloid and casein rods or tubes and also of rubber tubes, has, in recent years, been adopted for many of the new thermoplastics and even for thermo-setting resins.

The method is essentially the forcing of plastic by means of a plunger through a heated nozzle of simple circular or square cross-section if a rod is required. If a tube is to be made then a concentric mandril is introduced, the plastic being extruded in the annular space between the two. This method of producing cellulose acetate tubing, for example, is preferred by many users instead of the older method of shaping an oblong piece of thin sheet and then "welding" the seam. Much thicker tubes can be produced by extrusion, and the complete absence of a joint is welcomed.

Extrusion is now commonly carried out on the polyvinyl and polythene type of plastics for making electric cable covers and for producing continuous coloured strips or ribbons for shoe and belt manufacture. It is understood, also, that water and chemical piping of similar materials have been extruded in Germany.



Extruded phenolic resin tubes, etc.
The bottom example is a curtain roller suspension.



The versatility of the injection moulding process: 92 letters of Tenite cellulose acetate moulded in one mould.

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Within the last few years some extrusion of thermo-setting resins of the phenolic and urea types has been successfully achieved, notably in Great Britain.

The method adopted, although on broad principle the same as that utilised for the thermo-plastics, differs in the internal mechanism of the extrusion machine in that here the moulding powder must be compressed and heated to flow point in one section, heated until cured in another, and finally cooled on its way to the exit spacing.

The first successful extrusion of thermo-setting resins on a manufacturing basis in Great Britain was that carried out about 1936 for the production of duplicator cylinders by Gestetner Ltd. of London, using a phenol-formaldehyde moulding powder. It is still being carried out with great success. The machine employed is a Werner-Pfliederer extruder. This is a continuous automatic extrusion type and consists of a resin feeding chamber, a ram actuated by a hydraulic three-throw pump and an electrically heated die which feeds on to a mandril about $4\frac{1}{4}$ in. diameter. The extruded tube is thus this width in internal diameter and about $\frac{1}{4}$ in. in wall thickness. The following description of the manufacture is given in *Plastics*, June, 1937, p. 35 :

In order that there should be no clogging of the feeding chambers by premature curing, there must be no heating before the resin powder enters the die proper. The ram, therefore, first presses the powder into a chamber which is maintained at a low and constant temperature by cold-water circulation in a surrounding jacket. The resin powder is thus maintained in a compressed form some inches before it enters the die. The die or curing chamber is an annular space some 9 in. long and is progressively heated along its length by three electric elements "stepped up" to obtain successive temperatures of 130° , 160° and 180° C. As the time of cure in this 9-in. length is about $1\frac{1}{2}$ minutes, the ram works to an output of some 6 in. of tube per minute. About 14 miles of tubing have been turned out during the last year. The finished tube issues on the mandril and is sawn off in convenient lengths after close optical examination for faults such as scorching.

About 1938 British Industrial Plastics Ltd. produced extruded tubes of varying cross-section of urea resins with complete success, the beautiful colours thereby made allowed the product to enter the "home" trade in the shape of towel-rollers.

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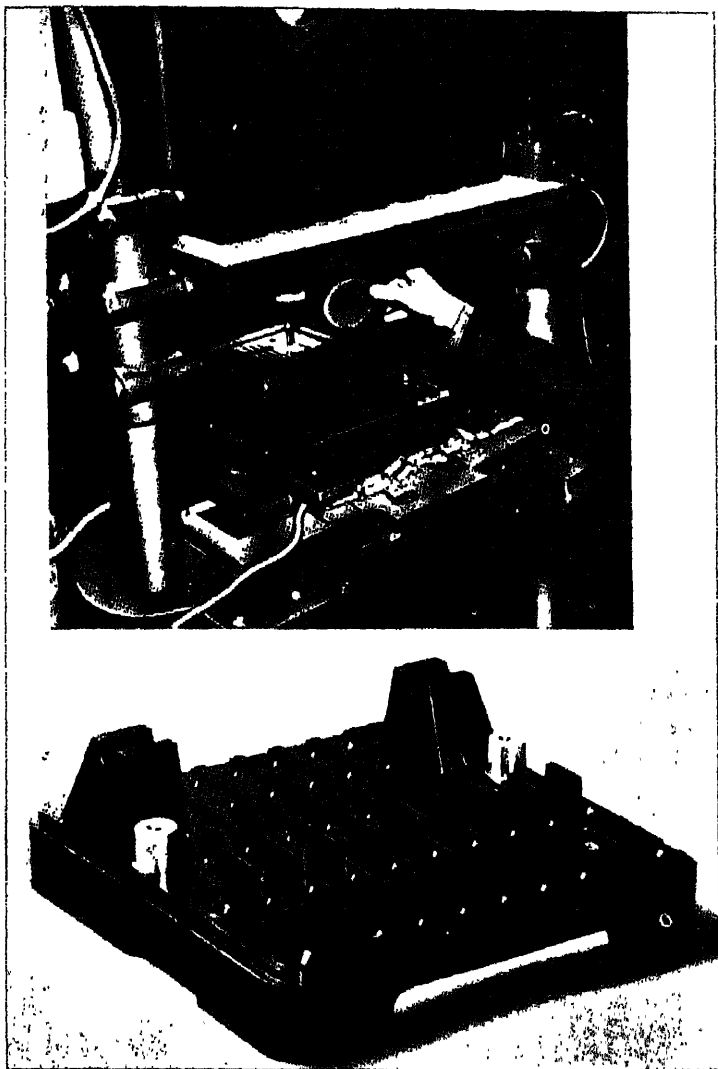
About the same time Cellomold Ltd. produced a wide range of extruded phenol-formaldehyde tubings of a cross-section especially designed for curtain roller suspensions. One of these shown facing p. 47 is probably one of the thickest and strongest plastic extrusions so far made.

Compression Moulding.—This type of moulding is carried out most commonly on the phenol and urea moulding powders, that is, the thermo-hardening synthetic resin plastics. It consists in placing a quantity of the powder or a compressed tablet of the powder in the lower half of a heated mould, held on the platens of a hydraulic or mechanical press. The top or plunger half of the mould is then lowered, slowly compressing the plastic, which, under the hot conditions of the press, flows into every cavity of the space between the top and lower halves.

In practice the quantity of powder required to make the finished moulding is carefully weighed with a slight excess and emptied into the lower cavity and the top plunger slowly lowered, using at first a comparatively low pressure of the order of 300 lb. per sq. in. for some few seconds. During this period the mould is not entirely closed, but soon the pressure is increased to slightly over 1 ton per sq. in. and the mould is finally closed. The moulds are heated by steam or electricity to a temperature of about 350° F. and the moulding is held therein until final hardening takes place. This period varies greatly with the thickness of the moulding, temperature, etc., but is generally of the order of $\frac{1}{4}$ minute to $1\frac{1}{2}$ minutes for thin or relatively small objects. Obviously, before carrying out continuous production a number of tests are carried out to ascertain the best temperature and curing times under which a particular moulding must be produced.

The plunger is raised as soon as the period of "curing" has elapsed and the finished moulding is either removed by hand or ejected with special pins. In most cases the moulding needs no finishing, with the possible exception of the removal of excess powder or "flash" that has been squeezed out between the upper and lower halves of the mould and which remains adhered to the moulding.

The moulds are made of special steels and when moulding urea powders must be chromium plated to prevent discoloration. It is interesting to note here that with the increased importance of rapid output the mould is usually machined to take more than one

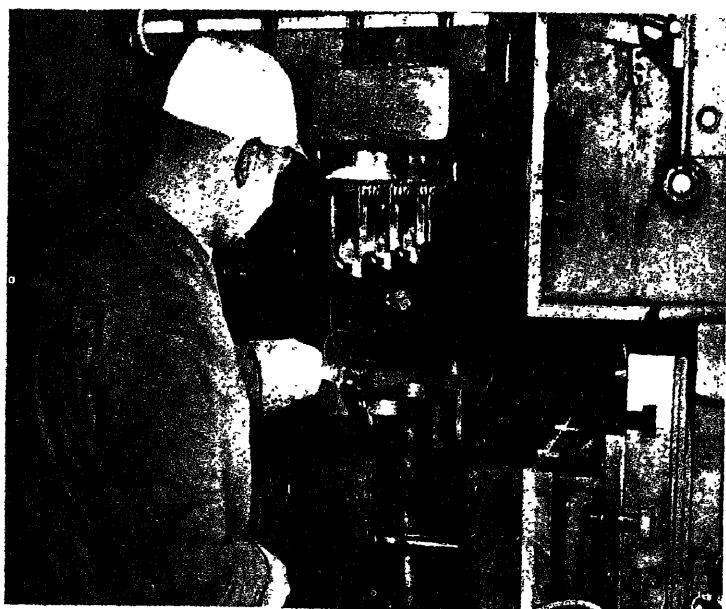
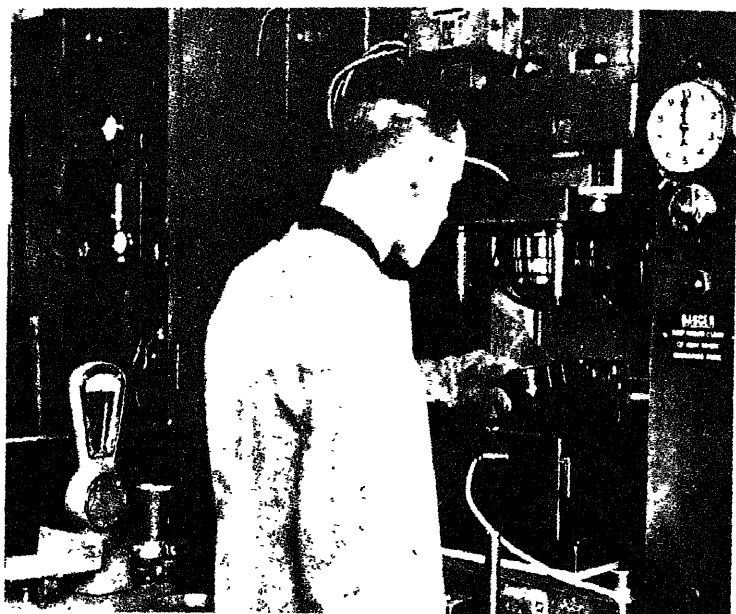


Compression moulding.

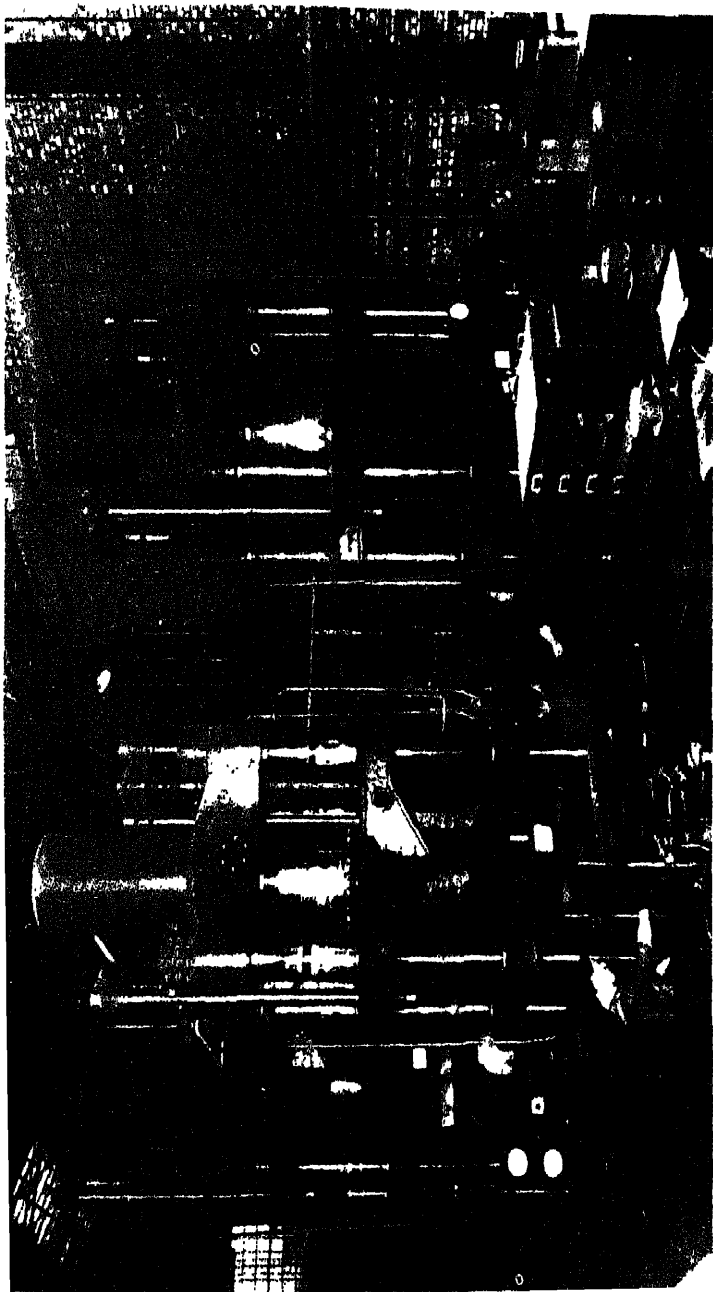
ABOVE: Loading the lower half of a mould with a cupful of moulding powder.

BELOW: The electrical component (fitted with two metal inserts) made from it.

[Facing p. 48.]



Two different types of presses used by Hoover Ltd. for moulding Hoover components from phenol-formaldehyde resin moulding powder.



Moulding radio cabinets at the works of E. K. Cole, Ltd., on 2,000-ton presses



G.E.C. mould weighing 5 tons, for producing 26 $\frac{1}{4}$ -inch light reflector from urea moulding powder.

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MOULDING AND FABRICATION TECHNIQUE

“shot” of powder. For medium-sized mouldings it is quite common to produce 4 to 6 in one mould, while in the small sizes, such as black piano keys, 30-impression moulds have been employed.

In the ordinary vertical plunger type of mould undercuts in the moulding are obviously not possible, but when undercuts are essential in the moulding, split moulds, in which the lower part is made in two sections and can be pulled apart sideways, are employed. Alternatively, side ram presses produce the same effect. The sizes and capacities of presses vary greatly, the small type being capable of exerting a total of 50 tons pressure and very large ones 3,000 tons, used for making radio cabinets and motor-car fascia boards. The largest mouldings ever made are believed to be the coffins made by the Ultralite Casket Co. of Stalybridge, England. The amount of moulding powder used in these compression mouldings is over 90 lb. without the lid.

An interesting development in compression moulding that has been carried out for many years is the simultaneous incorporation of metal inserts in the moulding. This is of considerable importance in the electrical industry, where, for example, a threaded insert is utilised to receive a screw. Again, for purely decorative purposes, metal filigrees may be placed in the bottom of the die, prior to the addition of the moulding powder, so that the filigree becomes one with the finished moulding.

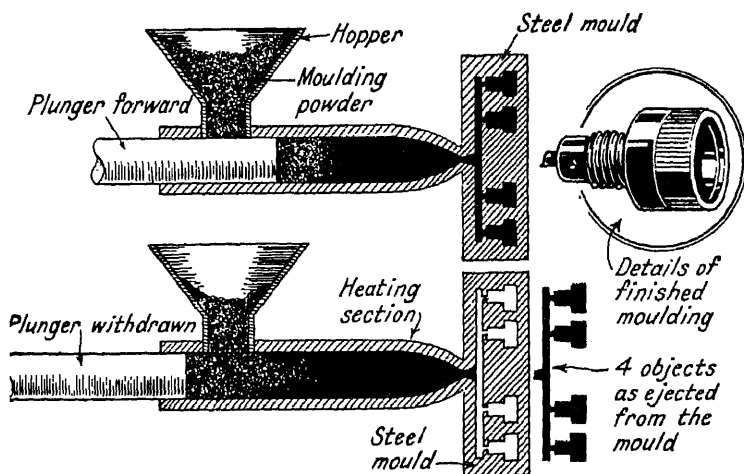
Injection Moulding.—In broad outline, the process of injection moulding, in which the moulding powders are almost universally the thermo-plastics cellulose acetate and polystyrene, consists in softening the powder in a heated cylinder and then forcing the plastic by means of a piston into a cold metal mould that is kept closed during the moulding operation. This pressure by the piston is maintained until solidification takes place in the mould. The piston is then withdrawn, the mould is opened and the finished moulding is ejected. (See illustration page 50.)

The machines can be vertical or horizontal; some are semi-automatic or totally automatic. The advantage of the horizontal type is the ease of feeding and ease of emptying the moulds. On the other hand, the horizontal press is generally used for the production of smaller moulded objects, while the vertical presses can more readily be worked for mouldings of 4 oz. and over. In this country it is rare to encounter such heavy injection mouldings,

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although machines such as the "Lester," which is a horizontal type with a capacity of 12 oz., are now in use in England. They are, however, quite common in the U.S.A. and Germany. In the former country even small fascia boards for automobiles have been injected from cellulose acetate. The heaviest injections so far made have been about 12 oz. in weight.

In the horizontal type the mould is almost always a multiple mould, that is, from two to, say, ten complete objects are made at every injection. The fluid plastic enters the mould through a narrow "gate" and spreads through channels to the dies. Thus,

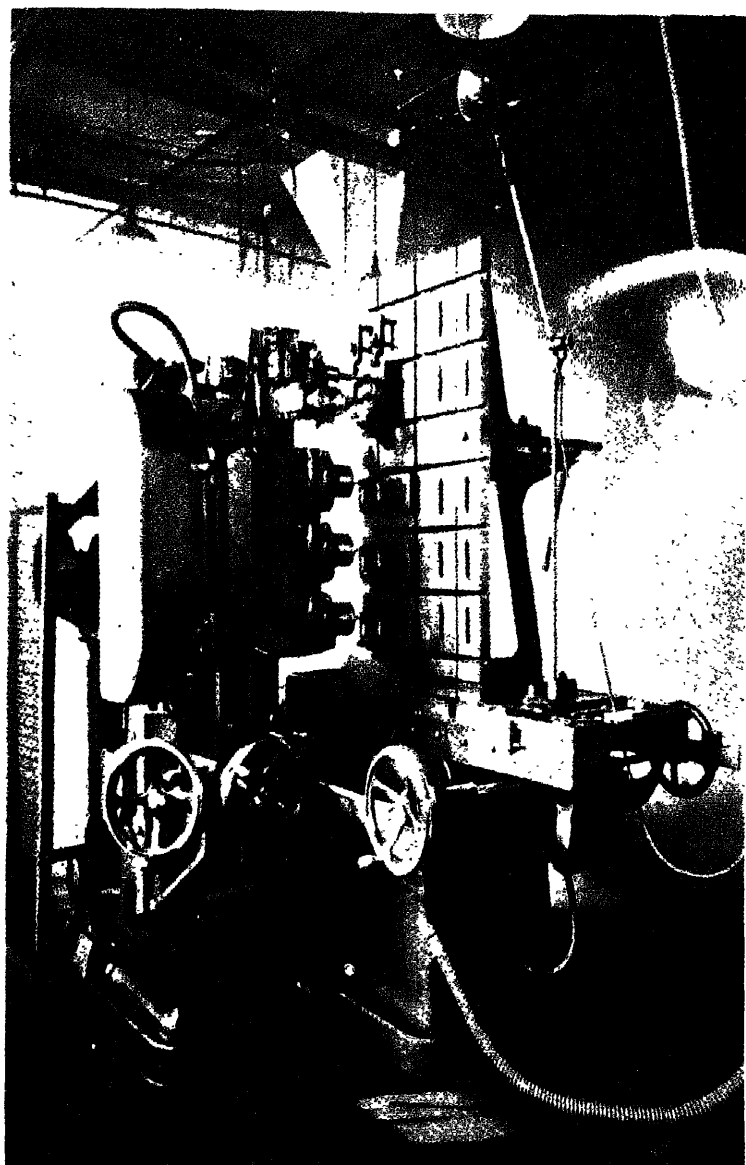


Simple diagram showing essential features of injection moulding.

when the mould is emptied the moulded objects are ejected together because they are connected by a thin strip of plastic. This connecting strip is easily removed and the mouldings need little or no finishing operations.

The ease of operation of these machines and the rapidity of production by them has greatly increased their popularity in the last two years. Assuming an 8-impression mould and a 20-second moulding cycle about 1,400 small mouldings can be produced every hour. To-day, combs, radio-knobs, bottle-closures, coat-hangers, watch-cases, fountain-pens, and a host of other objects are thus being made.

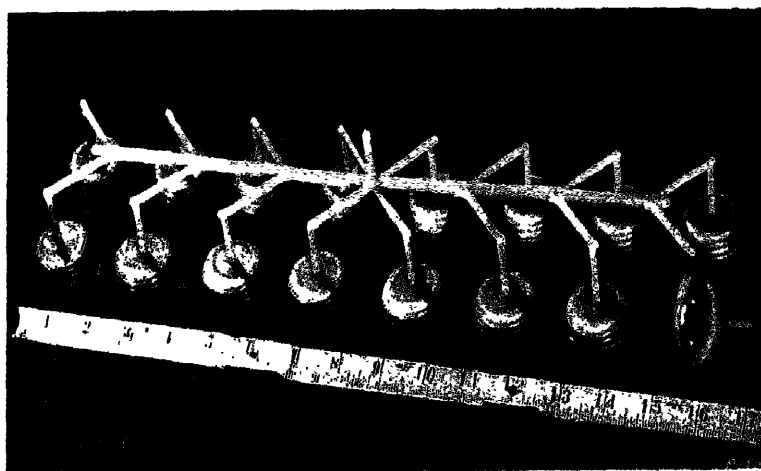
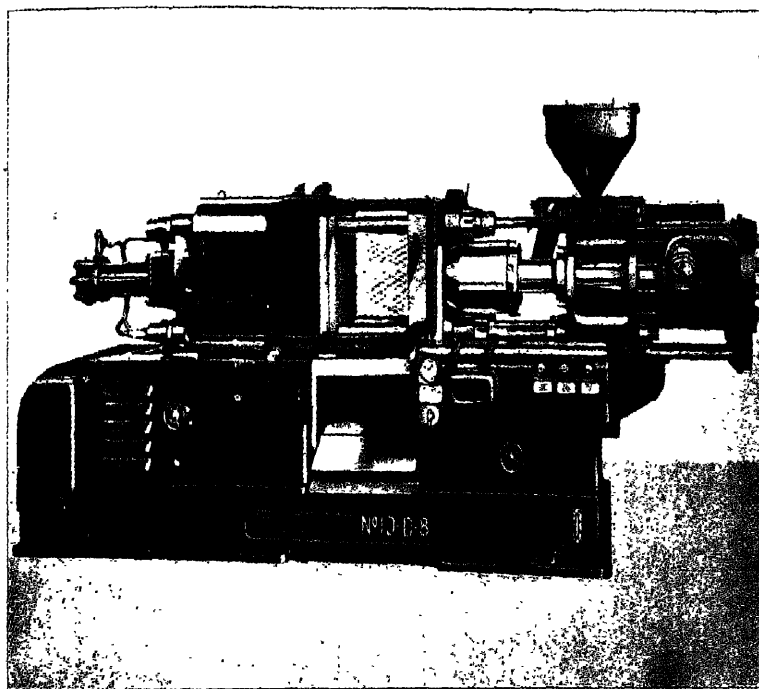
A specialised application of injection moulding that began in



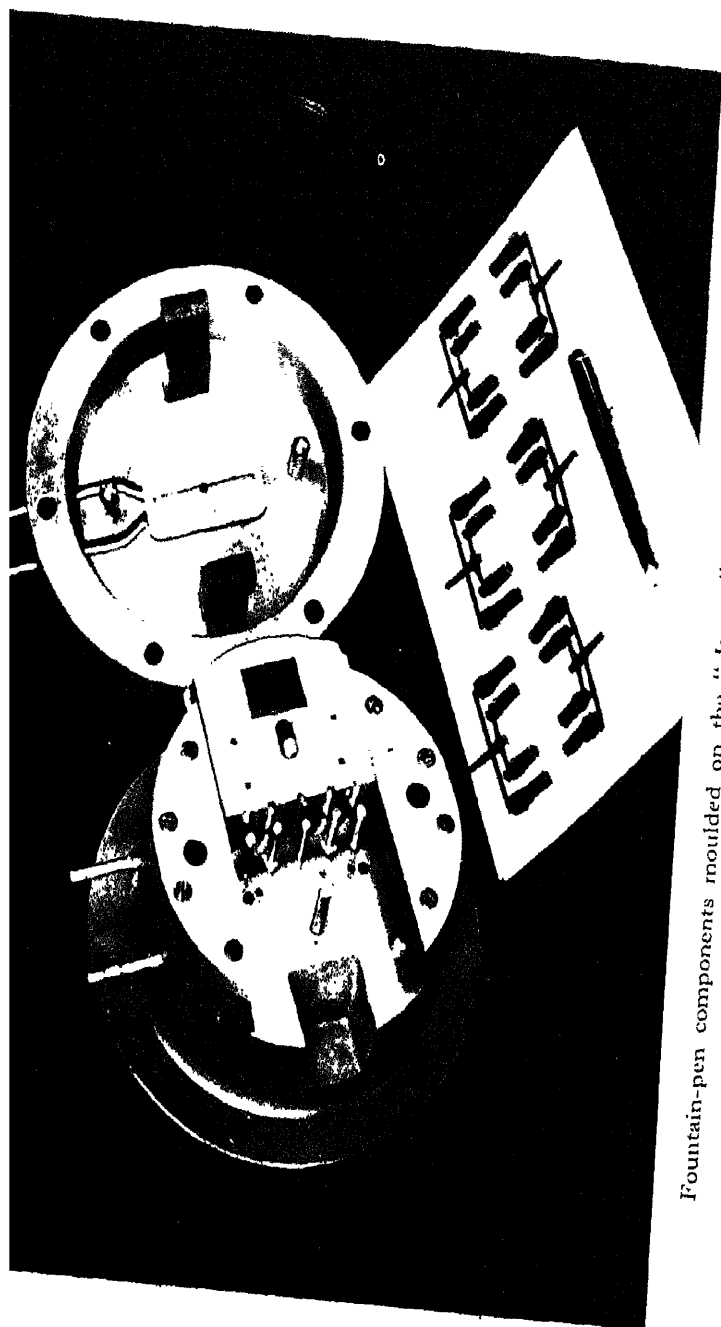
The Keller diesinker produces automatically all kinds of dies.

(Courtesy : Alfred Herbert, Ltd.)

[Facing p. 50.]



The Reed Prentice injection moulding machine and (below) ferrules for motor-car door and window handles made on it.



Fountain-pen components moulded on the "Isoma" automatic injection machine.
The mould is seen above.

MOULDING AND FABRICATION TECHNIQUE

Australia by Die Casters Ltd. is the injection of cellulose acetate round a metal die casting for the production of high-strength objects. This method has especially been applied to motor-car door-handles, where the all-plastic handle would scarcely have proved satisfactory, unless made of high-shock material.

As we have already indicated, the general practice is to use thermo-plastics in injection moulding. Some workers have successfully employed thermo-setting resins, and claim a great future for them, in the injection moulding of small articles.

MACHINING OF PLASTICS

All plastics can be machined although, obviously, some are not amenable to such ready machining as are others. Broadly speaking, the thermo-plastics are simpler to machine than the thermo-setting resins, and in the thermo-setting class those containing no fillers are easier to machine than those containing fillers.

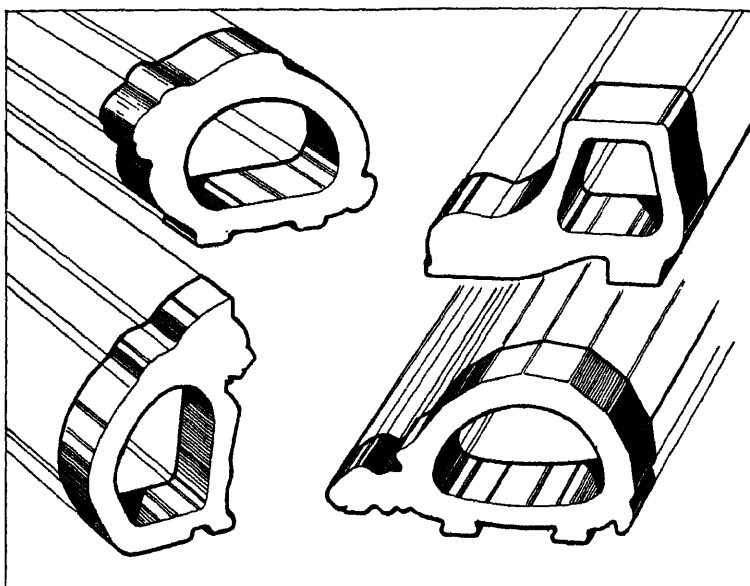
There is no need to stress the point that for injection or compression moulded objects there is no need for after machining, since the moulding, with rare exceptions, is ejected ready for sale. Indeed, the whole conception of the design of the mould is to avoid after finishing and provides holes, threads, etc., already sunk or cut.

Machining, therefore, refers rather to the sheet, block, rod, or tube that is produced in thermo-plastics, in cast and extruded resins or in laminated material.

Thermo-plastics.—There is little to add to the notes already given under "Blowing and Forming." All the thermo-plastics can be bevelled with rotary cutters, cut with guillotines, although in very cold weather they should be warmed slightly, punched and sawn by standard machines and tools. Circular holes can be drilled with the normal twist drill, but if thick sheets are used warming is again advisable. Filing, profiling and turning is carried out in the same manner as with wood. Casein and acrylic resins in sheet, block or rod form are especially suitable for this treatment, and wonderfully colourful or transparent objects of high artistic merit are thereby produced from them. Especial reference must be made to the great merit of acrylic resin. The sheet cuts as easily as ivory and is especially amenable to the art of turning. The remarkable optical properties of this plastic provide very pleasing effects when the surface is cut.

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Cast Resins.—The principle forms that are usually machined are the cast and extruded shapes, the former without filler and the latter with filler. The cast resins are supplied to customers in the fancy goods, cutlery and allied trades as extruded rods and tubes, which resemble the finished article in which the material reaches the market as closely as is convenient. Thus, manufacturers of "draughts" or "chequers" receive cylindrical rods which can be sliced and turned without much loss of material.



Profiled cast resin tubular shapes sliced to make table-napkin rings of interesting designs.

On the other hand, castings may be made to the customers' own designs. This form is readily seen, for example, in the accompanying simple design for children's table-napkin rings in the form of a rabbit, etc. The casting is merely sliced into 1-in. lengths, a hole is bored for the eye and the ring is finally polished.

Cast sheet may be sawn by circular or the band type, the teeth of which must be set for proper clearance and run at a speed of 1,200 ft. per minute. The band type is commonly used for cutting out letters and similar fretwork. In turning operations on rod and tube, high-speed tools are economical and best for long runs,



Knife-handles, tube and spherical display fabricated from Catalin cast resin.

[Facing p. 52.]

MOULDING AND FABRICATION TECHNIQUE

but standard tools may be employed. Rods and sheet may be tapped, but it is best to work with coarse threads.

On the whole, the machining properties resemble those of hard wood or brass. Any type of saw can be used, and suitable drills are those used for brass. In turning and milling operations the same feed and speed as in turning hard wood are employed. Cast resins always need polishing to bring out the best results. The standard buffing wheel can be used, but for small objects, such as jewellery, tumbling in pumice and then damp hard wood sawdust is more convenient and very efficient. A final polish can be given by tumbling with clean shoe pegs and a wax compound.

Extruded Phenol-Formaldehyde Resins.—It is rare that any machining or finishing is carried out on extruded plastics other than a simple sawing into standard lengths. The industry of extruded plastics, as we have already pointed out, is not yet widespread, but the concerns that employ them have gained considerable information regarding their machining. In the production of duplicator rollers, for instance, Gestetner Ltd. grind the outer surface and polish to the perfect condition required for the job. The inside rims at the two ends are then bored to a short depth to receive two moulded closing “ends.” In the early days it was considered impossible to bore this material, but the process is now quite efficiently done by using “Wimit” tools.

Laminated Materials.—Laminated plastics reach the customer in the form of sheet of varying thicknesses, blocks, rods and tubes to be machined into components for the electrical and engineering industry.

Punching is readily carried out on all types of laminated material. Thin sheets of the order of $\frac{1}{32}$ in. can be punched cold, but should be heated for greater thicknesses. Small gears for gramophones are thus produced by the strip.

One of the most interesting industrial developments of this material is the production of silent gears from very thick sheet or block. The sheet is first cut into circular gear blanks by means of a band saw or by trepanning. The teeth are then cut by any of the standard methods and machines—milling machines, gear cutters, and shapers. All the manufacturers of the raw material issue comprehensive instructions as to feeds and speeds for ensuring the best results and obtaining fine accuracy.

Generally speaking, there is no difficulty in carrying out any

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of the usual machining operations with the well-known types of machines. The material can be drilled accurately, milled and shaved, countersunk, turned, tapped, and screw-cut with tools of high-speed tool steel or of the Widia type.

CHAPTER V

ENGINEERING AND CHEMICAL MACHINERY AND PLANT

IN no other industry has the entry of plastics been watched with more anxiety and hope than in the field of engineering. The reason is not far to seek, for not only was the engineering world up to the 1920's concerned in practice and in thought with metals as almost the only possible materials of construction, but also because any non-metallic substance that did obtain a foothold in this stronghold of metal tradition did so in the face of considerable opposition, as a result of prolonged testing under extremely severe conditions and because it was eminently suited for the job. In a very important sense, therefore, the entry of plastics into engineering raises their status to levels higher than they have ever reached and holds out much of still greater promise as and when the special properties are realised and appreciated.

LAMINATED AND ALLIED MATERIALS

It was probably only about fifteen years ago that the first steps to present a reasonably strong plastic material to the industry were taken. The early specimens of impregnated laminated materials had been examined and were full of promise for at least one important branch—the production of gear-wheels, pinions and the like, for such preliminary examination indicated a silent gear more lasting than the old raw-hide type. The first laminated materials were of compressed resin impregnated paper, but although extremely promising, they failed because of rapid wear of the gear-teeth. The complete solution was found by replacing paper with fabric, which gave the needed toughness under load.

Gears.—The raw material for the production of gears is in the form of a block or sheet (varying from $\frac{1}{8}$ in. to 5 in. thick) made by the cohesion under high pressure and heat of sheets of resin impregnated fabric. This fabric may be a strong cotton duck

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or canvas for heavy duty gears and pinions or a finely woven cotton of very light weight for making the small gears used for gramophones or electric clocks.

There has now been made available a wide range of gears, with complete success, ranging from thin and small gear-wheels up to sizes as large as 5 ft. in diameter and 10 in. thick for especially heavy machines. A welcome property of the laminated fabric is the comparative ease with which it can be treated by the usual operations of sawing with band saws or trepanning tools and cut and otherwise worked by turning, drilling, milling and shaving. Spur, bevel and helical gears are all types of common production.

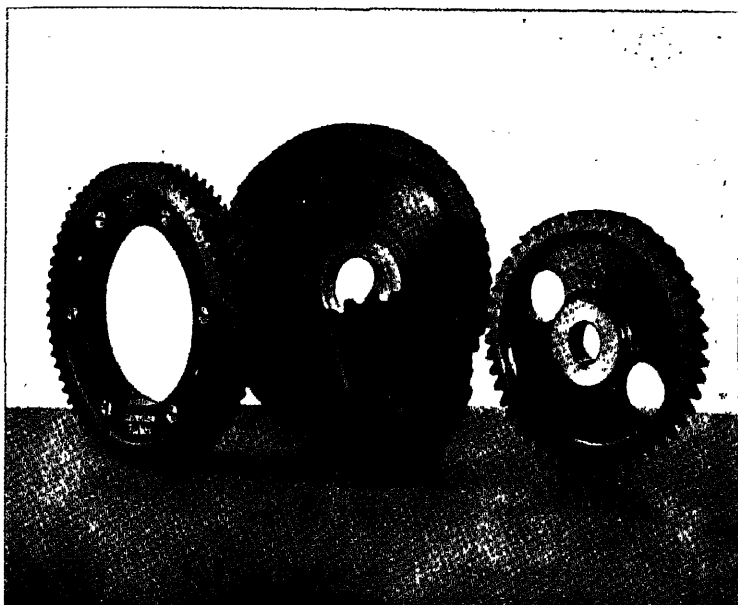
To sum up, the properties of the laminated gear that make it superior to the metallic type are :

1. Silent in action.
2. High strength per weight ratio.
3. Low modulus of elasticity (about 50,000 lb. per sq. in.), making it many times more resilient than steel. Laminated material can thus absorb shocks and intermittent stresses which can break down metal gears.
4. It is stable under all working conditions and resists the action of oils and many acids and alkalis.
5. Will not score metals.

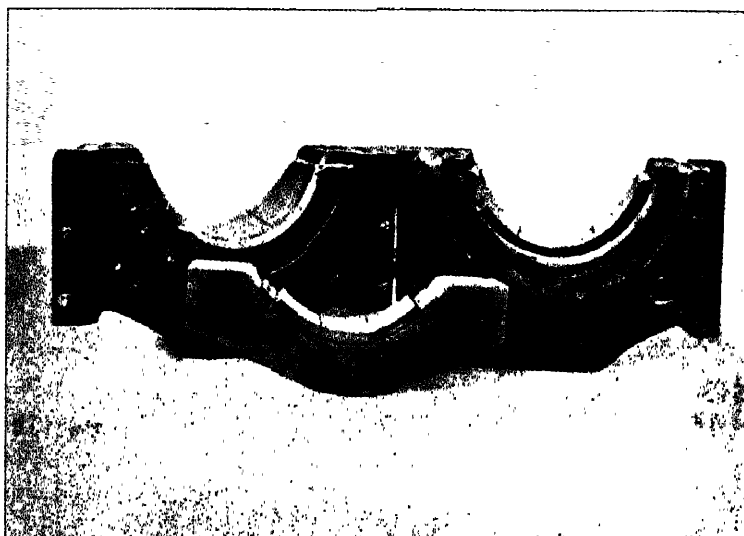
In actual works practice the above advantages have been fully proved over many years' service. The gears are really silent and can allow of the disposition of heavy machinery in places where noisy machinery cannot be allowed. There is the added advantage of having no deleterious effect on the actual workers because of excessive noise. They outlast metal and rawhide gears, need no lubrication, except the rare application of a little graphitic oil, and, finally, the resistance to shock adds longer life to the machines themselves.

It is important to note at this point that such gears (although not very large sizes) can also be moulded in high-pressure moulds, thus avoiding all cutting operations. The raw material for such production is either a flake or "chopped" form of the impregnated fabric, or yet another moulding material made by impregnating flock with an emulsion of phenol-formaldehyde resin. Both moulding compounds are made into extremely tough gears.

Bearings.—The production of bearings for light and heavy

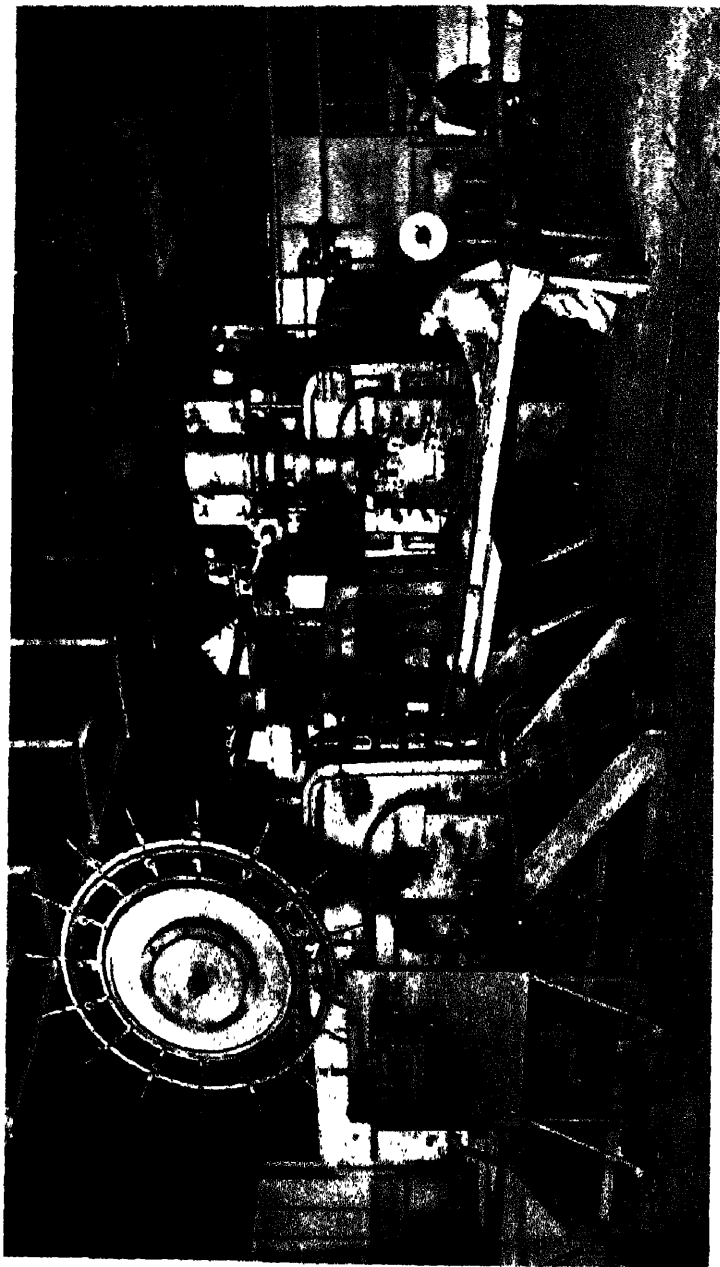


Gear wheels fabricated from resin impregnated fabric (Turbox).



Close-up of laminated bearings as used in steel rolling-mills.

[Facing p. 36.]



These steel rolling-mills are fitted with roll-neck bearings made of laminated fabric (Demag).

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machinery followed soon after the success of the plastic gears, for the qualities required in the one are similar to those required in the other. The raw material for these bearings is practically the same as that used for gears, namely, the formation of a solid block by the compression under heat of resin impregnated fabric, or the flake form for moulding purposes made by the reduction of impregnated fabric into small pieces.

A good example of the mechanical properties of a well-known laminated bearing material is as follows :

Specific gravity	. . . .	1.3-1.4				
Tensile strength	. . . .	7,500/8,000	lb. per sq. in.			
Resistance to bending						
(a) Vertical to laminations	. . . .	over 16,000	„ „ „ „			
(b) Parallel with laminations	. . . .	15,500	„ „ „ „			
Compression strength (vertical to laminations)	. . . .	41,000	„ „ „ „			
Modulus of elasticity	. . . .	75,000	„ „ „ „			
Brinell hardness	. . . .	40				

It is stated that the flake material mentioned above, although giving slightly lower figures in mechanical tests, provides a finished product with a coefficient of friction much lower than that of the laminated material. Bearings have been made from the moulded flake material with a backing reinforced by laminated sheet.

As with the silent gears, the bearings run with little or no lubrication. In practice, the lubrication is generally made by water. Thus, not only is there a great saving in lubrication costs, but the water serves to cool the bearing, which, because of its low heat conductivity, would otherwise tend to heat up.

Indeed, heat conductivity and frictional resistance are the most important features of a bearing and, since the application of a lubricant, such as water, readily absorbs the heat generated in the plastic bearing and, since, also, the coefficient of friction is very low, especially at low speeds, the new bearings approach the ideal for metal rolling mills.

To sum up, the advantages of the resin impregnated laminated bearing are :

1. Low coefficient of friction. One published test showed that, using water as lubricant, it is about $\frac{1}{4}$ to $\frac{1}{3}$ that of the coefficient of friction of an oil-lubricated white

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metal bearing, under running conditions of 400 ft. per minute and 500 lb. per projected sq. in. of projected surface.

2. Reduction in power consumption and in time, due not only to above in normal running, but also in starting up from the cold.
3. No tendency to score the shaft, rolls run smoother, and there is less necessity to adjust rolls due to wear.
4. This, in turn, gives greater regularity of product, and absence of oil gives a cleaner product.
5. Plastic bearings last three to four times as long as bronze bearings.
6. They are unaffected by acid atmospheres and cannot rust in humid atmospheres.

The foregoing properties, especially resistance to wear, oils, greases and solvents, and the ability to dampen vibration and shock, make the same material attractive for many other engineering components. It is eminently suitable, for example, on flexible couplings to relieve end thrust and is so widely employed in the U.S.A. The same product, in the form of moulded rods, makes excellent drive or shear pins which, on shearing on overload, do no damage to metal parts since they are non-scoring. *Modern Plastics*, October, 1938, p. 262, describes the value of laminated impregnated fabric in a new mechanical application because of its high resistance to temperature changes. In casting inserts into iron or steel it is necessary that the inserts be held rigidly and accurately in position during the core baking and casting cycles. Plate- or tube-laminated material is machined to support and locate the inserts properly, while the core is formed and baked and becomes an integral part of the core as it is placed in the mould. Thus, the inserts cannot be displaced and ensure a perfect moulding.

Suction-box covers of great length, on foudrinier and other paper plant, have long been employed, replacing and outlasting wood in a water-laden machine.

A host of smaller units made of fabric base find employment in a diversity of fields—as oil-pump gears, thrust washers, gaskets, pump vanes, ball-bearing retainers, thrust collars, truck wheels, picking sticks for textile looms, friction cone heads, doctor blades

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on paper-feeding and similar machines where metal should be avoided, owing to danger of spoilage of the manufactured goods by rust.

Another form of laminated product, that made up of laminations of wood, should be especially attractive to the engineering world; although its applications outside the electrical and aircraft industry have been limited. Most of the industrial countries make this type, some of the best known appearing under the trade names of Permali (English), Jicwood (English), Jabroc (English), Permali and Durisol (French), Lignostone (German), etc.

The methods of manufacture differ slightly. In some instances the thin sheets of seasoned wood ($\frac{1}{1000}$ in. and upwards in thickness) are merely coated with a synthetic resin solution and then compressed under heat; in others, layers of Plybond or Tego film (resin-impregnated tissue paper) are placed between the sheets of wood and compressed; or, yet again, a third method, for example that adopted in making Permali, the sheets are impregnated under pressure with an alcoholic solution of resin, solvent is removed under vacuum and a number are compressed and heated under high pressure. Whatever the process, however, the finished material appears as a sheet or block—hard, acid-resisting, non-warping, of great mechanical strength and excellent dielectric properties. Blocks 10 in. thick have been produced. Moreover, within limits, the impregnated sheets can be moulded into slightly curved or other simple shapes. As indicated on page 86 such material is widely used for the construction of electrical components, such as busbars, transformer rings, insulating fish plates, radio insulators, transmission line cross-arms, core side plates, core wedges, and many different types of electrical machinery. In addition, aeroplane propellers are built, and boats, especially of the kayak or canoe type, have formed an important outlet for the material. Yet another interesting development, although not yet apparently a commercial success, was the building of barrels for holding corrosive liquids and salts. Apparently the industry concerned in buying such containers are loath to adopt them, at present, but we hope that interest in them will not disappear altogether, for we regard such acid-resisting barrels a logical replacement of lined barrels and kegs, some of which are not so successful as they might be.

The first application of laminated and impregnated wood in

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the engineering world, outside the electrical field, we have encountered is also perhaps the largest ever made. It is a mortar built up from Permalin, made by the French concern, for the mixing of dynamite, and consists of a very solid circular structure in trough form to allow mixing of keiselguhr and nitroglycerine by rotating rollers. So new is this application that details are lacking, but presumably a strong acid-resisting material, resistant to abrasion, non-metallic and non-sparking was required. In size it is impressive, being about 12 ft. in diameter and 24 in. high.

It is not difficult to imagine that impregnated and compressed wood is, as corollary to the airscrew, perfectly suitable for the fabrication of the large type of air-extractor fan utilised in coal-mines, gasworks and the like. They are now widely employed where oil- or acid-laden gases must be extracted for washing or other purposes. Their non-sparking properties make them especially attractive.

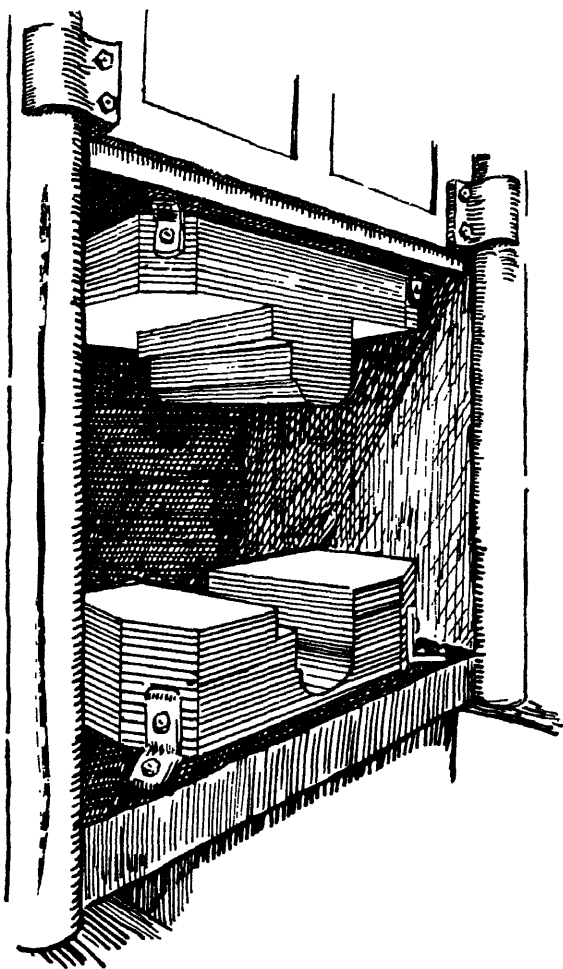
Of comparatively recent interest is the use of resin-impregnated wood for making press tools instead of heavy metal castings which can only be machined with difficulty. The advantages claimed for the resin-impregnated wood (Jabroc) may be summarised as follows :

1. Ease and rapidity of machining on standard lathes.
2. Adaptability to series production in aircraft manufacture which usually entails modification of the design at least once before actual production is put in hand.
3. Lightness in weight. This is considerable as the specific gravity is only 1.3 to 1.4, that is, about $\frac{1}{3}$ to $\frac{1}{4}$ that of steel. Lightness in weight facilitates handling and setting up of machines and so increases the tempo of production.

Stamping tools fabricated of resin-impregnated wood are now in regular use in aircraft factories for turning out aluminium, aluminium alloy and steel sheet pressings and they have an average life of approximately 2,000 to 2,500. When the tools show signs of wear they can, of course, be built up and re-used. In spite, therefore, of the relatively high cost of this non-metallic material when compared with steel, its working properties are such that considerable economies can be practised in the works and its use facilitates increased production. Resin-impregnated wood

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tools are particularly suitable for rearmament work where speed is of the utmost importance.



Press tools made of Jabroc, resin-impregnated wood.

CHEMICAL PLANT

By far the most important engineering constructional work in synthetic resin materials has taken place in the chemical and allied industries. This is due, first, to the fact that, more than any other, the chemical industry is so much concerned with the effects

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of corrosion and, secondly, as a result of the first, the chemist is more ready to examine new materials of construction than the engineer, who rarely deals with corrosion problems other than simple rusting.

Chemical manufacture entails a host of chemical engineering processes—storage and pumping, distillation, evaporation, heating in open or enclosed vats, drying, filtration, washing or extraction in towers, etc. etc., and utilises concentrated and weak acids both inorganic and organic, alkalis, salts, organic solvents, etc., and, to fight corrosion against these, special metals such as platinum, gold, silver, stainless steel, lead, copper, aluminium, silicon iron, earthenware and fused silica, glass linings, rubber and wood have long been employed. Many of these have serious drawbacks, such as cost in the case of the first four named above, brittleness in the case of silicon iron, earthenware and fused silica, the disadvantage of imparting impurities by some and the limited corrosion resistance of others.

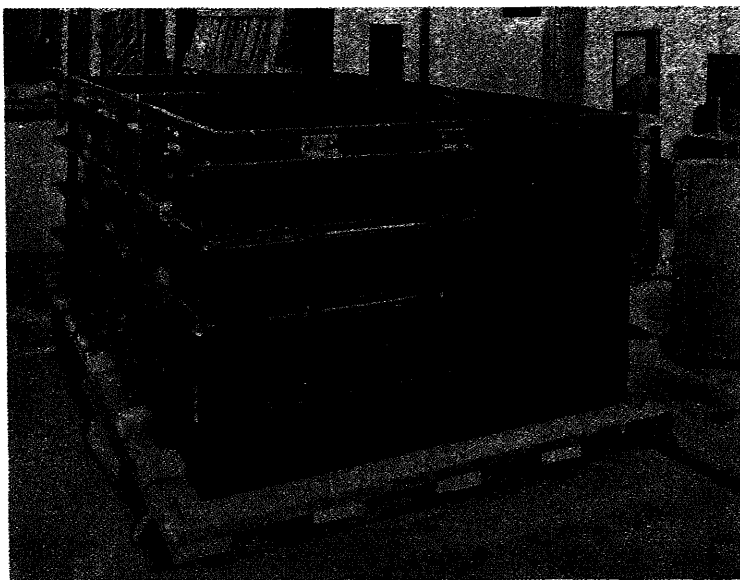
Although the important corrosion-resisting properties of phenolic resins have been known since their inception, the application had been limited because of the difficulty of making the large structures necessary, the normal method of moulding in expensive moulds being quite out of the question, since repetition work in the chemical industry is comparatively unknown—the size of two tanks, for example, is rarely the same. It was only until the stage of utilising simple and inexpensive moulds was arrived at did the construction of single pieces become economically possible.

To-day three important concerns are carrying out the construction of a large range of plant from mixtures of phenolic resins with fillers, generally carefully selected asbestos fibre. They are Kestner Evaporator & Engineering Co. Ltd., London, who produce the finished plant of the plastic known as Keebush, the Saureschutz G.m.b.H. of Berlin, Germany, who make it of Haveg and the Haveg Corporation of Newark, Del., U.S.A. The raw material and methods of construction are probably the same in all three companies.

Although actual details of production are lacking, it seems probable that the mass of resin-impregnated asbestos material is first made into sheets or slabs, which are then lined into a simple mould, such as a tank. Heating converts the material into the



Absorption tower 35 ft. high of Keebush resin.
Constructed in 5 sections and fitted with Keebush sprays, grid-plates, etc.



Large two-chambered acid tank constructed of Keebush.

(Photos by permission of Kestner Evaporator & Eng. Co.)

[Facing p. 62.]

ENGINEERING AND CHEMICAL MACHINERY

hard and tough finished form and it is then separated from the mould. In the case of a pipe, the sheets are wound round a removable mandrel which can be heated to effect the curing of the resin and then withdrawn.

The extent to which Keebush and Haveg have been accepted by the chemical industry is reflected in the very varied type of plant that has been made. Cylindrical tanks for storing acid up to 10 ft. diameter by 10 ft. deep and of wall thickness $\frac{3}{4}$ in. have been made, moulded in one piece. This means a capacity of nearly 5,000 gallons (20 tons of hydrochloric acid). Such a tank is sufficiently strong and needs no reinforcement. Larger tanks are provided with exterior steel bands or wooden holding structures. Towers for washing gases have been produced in sections and assembled by split metal rings. Such structures, with bottom inlet pipe and top exit pipe and fitted with perforated shelves to hold the packing units, have been built 3 ft. in diameter and 10 ft. high. Pumps, agitators, fans, crystallising pans, drying trays, filter press plates, steam injectors, pickling tanks, dye vats, low temperature stills, buckets, pipes, bends, bolts, etc., are now being used industrially.

The literature supplied by the Kestner Evaporator & Engineering Co. Ltd. states that Keebush is especially resistant to :

Acids and Salts.—Hydrochloric acid, all strengths ; sulphuric acid up to 50 per cent., sulphurous acid, all organic acids, iron, aluminium and zinc chlorides. A special grade withstands hydrofluoric acid.

Alkalis.—Ammonia, lime, sodium carbonate, neutral soap solutions. The special grade referred to above withstands caustic soda and potash.

Solvents.—Hydrocarbons, alcohol, carbon tetrachloride, etc.

General.—Chlorine, sulphuretted hydrogen, hydrogen peroxide, aluminium sulphate, ammonium sulphate, etc.

It does not withstand the strong oxidising acids, nitric, chromic and concentrated sulphuric.

Equally important are the physical properties. For Haveg the compression strength is about 5.2 tons per sq. in. and the bending strength about 2.8 tons per sq. in. About $\frac{1}{5}$ the weight of steel, the material provides saving from the point of view of installation, holding and supporting structures. It has a homo-

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geneous, smooth and impervious structure, so that cleaning and maintenance is simple. It readily withstands sudden change in temperature (the upper temperature limit of normal working is about 130–140° C.), a property not possessed generally by glass-lined or silica vessels.

As for the important question of length of life of plant made from these plastics, it is interesting to note that some of the earliest applications were in the form of metal pickling tanks which have been in use for more than ten years and are still working without trouble. Large and complicated pickling tanks, some 60 ft. long and fitted with inlets for acids, steam, water and compressed air for agitation, have been constructed completely of this type of synthetic resin. The makers claim that in certain instances the efficiency of pickling plant has been increased by 100 per cent. and more.

In addition to the moulding or building of solid structures, Haveg and Keebush are both available also in the form of a cold setting plastic which can be used by the worker on the site to patch repairs, to set tiles, to make joints and so on. The asbestos-resin compound is mixed on the spot with an alcoholic solution of sulphuric acid and is worked with a trowel as with ordinary cement. It soon hardens and becomes quite insoluble.

Dekorit.—Yet another form of solid resin structure that has recently appeared in chemical engineering is the cast moulding. As described in a previous chapter (p. 20), liquid phenol-formaldehyde resin, without fillers, can be poured into simple moulds of lead or glass and when cured, usually after several days, or even weeks, at a controlled temperature, are removed in the solid form. Thus a rod or tube or other simple shape is made, which can be readily cut into slices, short tubes, cubes, etc., according to the profile. Manufacture was until recently confined almost solely to producing small parts for the fancy goods and imitation jewellery trade, but an interesting advance has already been made beyond this. The *Queen Elizabeth*, the newest of British transatlantic liners, is fitted with some thousand or so lavatory seats cast in solid resin.

The earlier types of cast resin suffered somewhat from liability to shrink, to gradual change in colour. This was probably due to the difficulty of reaching finality of cure, which normally continues for some period after the casting is removed from the

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mould. In addition, although the water absorption is low and quite suitable for normal purposes, it is probably not quite suitable where continual immersion in water or other liquids is required. These drawbacks have until recently held back wider application of cast resins, especially in the engineering industry.

The latest researches, however, have resulted in the production of a much superior cast resin by Chemische Fabrik Dr. Raschig, G.m.b.H., the German chemical concern headed by the well-known chemical engineer who for many years has produced the normal type of phenolic cast resin.

The new resin is called Dekorit F, the following claims being made for it. It is a fully cured material and is thus completely dimensionally stable. It is also free from porosity. It possesses all the advantages of ordinary cast phenolics, being very hard and heat-resistant and, it is claimed, is even somewhat superior to them in these respects. Like all cast resins, it is resistant to all acids, except certain oxidising acids such as nitric, and also resists action by mineral and vegetable oils and weak alkalis. It can be readily machined and cut, the hard alloy tools of the Widia type being most suitable. Thread and grooves are readily produced.

Dekorit is supplied in the form of rods up to 12 in. in diameter, in tubes, sheets and blocks for further manipulation. A cold-setting cement is also available for making joints, etc.

The applications so far appear to be solely in the field of chemical engineering and density meters, ball valves, large pipes for acid work, pistons, plugs for cocks, etc., are in use with considerable success. For example, a ball valve of Dekorit replacing a bronze ball has given good service for several months, with only slight mechanical wear. The usual life of a bronze ball is about 10 days. Pipes withstand pressures below 150 atmospheres, so that they are quite suitable for medium pressures. Like all similar resins, Dekorit has a low impact strength, so that presumably for large castings some kind of protection, such as a wooden housing, is desirable, if the situation of the plant warrants extra care.

Rubber in the Chemical Industry.

At this point it is important to mention that it is not proposed to describe the use of rubber in the chemical industry. This is somewhat illogical, for rubber is definitely a plastic. The reason is solely due to the fact that rubber has long had its technical

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journals and books and the subject has been thoroughly described for many years past. We can merely indicate that it is very widely employed mainly for the lining of hydrochloric acid storage vessels, towers, pickling vats and for the construction of pipes, cocks, buckets, ball-mills, barrels, pumps, centrifuges, fans, etc. Special rubbers are also available for withstanding cold 60–80 per cent. sulphuric and warm 20 per cent. acid ; it is also specified for acetic acid and sometimes phosphoric acid. Nitric acid (except in very low concentrations) attacks rubber rapidly.

The synthetic rubbers and other rubber-like material are not being used to an important extent for these purposes. Natural rubber is so much cheaper and is very efficient.

It is interesting to note that the lining of a reaction vessel for containing nitric acid and nitric acid salts has been carried out this year (1939) in England, using polyvinyl chloride sheet. The rubber-like type was used and is stated to be standing up very well under the oxidising conditions.

Miscellaneous.

The problem of piping for special conditions is extremely important to the engineer, so that the news that Mipolam, the German polyvinyl chloride resin, is being so employed is of considerable interest. It has been stated that Mipolam, which can be produced in a soft rubbery or hard horny condition, is utilised to replace lead piping where water is very soft. Since the material is completely inert there is no danger of water contamination and the possibility of lead poisoning is eliminated.

Although, as indicated at the beginning of this chapter that mouldings made from moulding powders have rarely been applied to engineering, yet the following example is of importance, as showing not only possibilities of construction, but the availability of high strength materials in this special branch of the plastics industry. At the famous London store of Harrods Ltd., a new series of escalators were installed early in 1939. Instead of beechwood slats, some 20,000 moulded ones made from a high strength Bakelite moulding powder were installed, fixed to a Bakelite laminated sheet. The slats, moulded with a serrated edge to prevent slipping have shown excellent service.

Transparent plastics may at first sight be considered only suitable for the manufacture of aircraft and for uses in building and

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art, but this is far from the truth. Of the transparent thermo-setting variety the urea resins have found some application in electrical spheres as switch covers and distributor covers where their transparency and high dielectric and non-tracking properties are both important, the former in tracing faulty connections easily.

As for the thermo-plastic group, such as the cellulose group (including celluloid) and the "acrylic" resins, these find many interesting applications, although generally of a subsidiary nature. An important use is for protective guards on working machinery to prevent accidents to workers, at the same time allowing for complete visibility. Simple glass sheet is rarely possible, while the stronger wired glass *interferes* considerably with the view. Cellulose acetate or "acrylic" resin sheet is the most suitable material.

Acrylic resins deserve additional mention since they possess certain characteristics which make them far more valuable for some purposes than the cellulosic bodies. They are not only much more transparent than acetate sheet and even glass, but they have a very low water absorption. Since in addition to sheet they also appear on the market in a granular mouldable form, they have been made into special shapes, such as bulkheads and accumulator boxes, where strength, transparency, water resistance and, in the case of the accumulator box, high resistance to acid, are essential properties. The "acrylic" resins also lend themselves admirably to use as sight glasses of low temperature processes or of the working of delicate instruments.

The rubber-like plastics and synthetic rubbers deserve special mention in this section for they have solved the ever present problem of swelling and solution by oil and grease. Neoprene, the Buna rubbers and Thiokol all find application in the fabrication of gaskets, valve-seat discs, washers, piston plungers, packings and oil-conveying pipes. Thiokol is also available as a moulding powder so that shapes of considerable complexity can be made from it.

The following additional miscellaneous list demonstrates the wide scope which plastics find in engineering:

Pulley blocks.	Conveyor chains.
Couplings for oil-well instruments.	Bolts and screws.
Axle bushings.	Tool handles.
Moulded fans.	Abrasive wheels.

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Further Possibilities and the Works Engineer.

There is little doubt, we believe, that were every works engineer to look round his own particular works he would find that plastics would solve many of his everyday worries and in many ways improve the efficiency of his plant and the quality of his final product by the installation of some of the components just described.

It is an obvious truism that corrosion and wear takes place in every factory, whether that corrosion is due to normal atmospheric conditions, or to extraordinary acidic or alkaline conditions. It is up to the works engineer to decide whether or no it is worth while installing non-corrosive material, but it is necessary to repeat how serious corrosion can be in factories which are by no stretch of imagination chemical industries.

At first sight it would seem that the food factories of the world should be among the most important users, since freedom from metal contamination and freedom from dirt are prime desiderata in such works. Metal contamination in the sense of the introduction of metal dissolved in foods beyond the permissible limits of food laws is extremely difficult to avoid. Such metal (generally present in the final product in some few parts per million) may be present in the raw materials or dissolved in transit or in treatment from the vessels employed in manufacture. It is not inconceivable that storage tanks, liquor-conveying pipes and certain other plant built of plastics would diminish the danger. Mixing plant employed for "cold" (below 120-130° C.) mixing also seems appropriate. High temperature boiling, such as in jam-making, is not possible with plastic structures.

A metal contamination different from the above also occurs (happily rarely) in food factories. We refer to the accidental occurrence of comparatively large metal pieces—broken bolts, nails, metal wire from filters and so on, which, on occasion, manage to escape the closest care and supervision. Even pieces of glass have been known to appear in the final product. It seems almost humanly impossible to avoid all such occurrences, but in general terms it seems obvious that the inclusion of plastic materials, where possible, should diminish the probability. At least we know of one concern that has installed "acrylic" resin protectors round electric lamps to avoid broken glass falling into food products.

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One of the most precious boasts of the twentieth-century food factory is the maintenance of cleanliness, both of personnel and plant. It is natural that the effort should be first applied to the food factory, but the necessity is there in all types of factories, whether they are factories making face powders, glue or photographic material. Purity of product is one of the important advances of this century. But of what avail is a worker working in a beautiful white smock if a rusty leaking water pipe is allowed to drip its red quota of iron oxide into a tub of finished goods, if grime is allowed to accumulate on walls difficult to clean, or if specks of distemper are allowed to float down on filling tables? Such simple protection as plastic-laminated wall panelling may be considered fantastically expensive, but the economic balance sheet against the elimination of yearly painting, ease of cleaning and resultant cleanliness has never, we believe, been made.

In this category must also be included the "mineral water" factory, which often manufactures, in addition to ginger ale, lemonade and the like, squashes of various fruits. The abundance of water, as well as acidic juices, is responsible for extensive corrosion. Pickle factories, too, call for special examination, for vinegar and nearly all condiments have destructive action on metal and wood.

In discussing the structural materials that are used for canning factories, T. W. Jones in a recent paper before the Society of Chemical Industry says:

From the point of view of bacterial contamination, the smooth surfaces of metals give them an advantage over wood which is difficult to clean and can retain enough foodstuff in its grain and cracks to provide excellent breeding ground for micro-organisms of all kinds. In considering the suitable metal, it must be remembered that it has to withstand exacting acid attack, particularly in the handling of fruits and vegetables. Not only are metals required for sorting and picking tables, but also in the construction of the various machines in which the food is prepared, such as blanchers, snibbers, syrup and brine tanks, syrupers, briners and filling plant. Furthermore, a good deal of corrosive fluid is spilt from cans on to conveyor belts. Another point to be considered is the possibility of the setting up of electrolytic couples between different metals in the same machine, whereby corrosion and contamination of the food is possible. This is a point to which far too little attention has been given by plant makers, and it is not unusual to see equipment with three or four different metals in contact one with

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the other and all thoroughly wetted with brine, syrup or juice. In apple-canning, iron can be a great nuisance, as an inky black liquid from the tannins in the juice can soon spoil the appearance of blanched apples, and here again, quite unsuspected sites for contamination are frequently found. For example, in an apple pre-heater the belt was made of Monel metal and the drum carrying it was constructed of wood, the shaft of the drum, however, was of steel, and the acid steam condensing on this formed an excellent black liquid which fell on to the belt and was conveyed to the fruit. Corrosion of galvanized iron guides in a conveying system has also caused unpleasant blackening when the zinc surface had corroded sufficiently to permit attack of the iron. Trace quotes the case of copper fingers of apple slicers which produced unpleasant green colorations. He also quotes the case of a syruper in which a Monel metal tank was carried on an iron frame. A green nickel salt was deposited at the point of contact with, once again, damage to the fruit. Pumps can be quite troublesome, and it may sometimes be necessary to replace the metal with *lignum vitæ*.

It seems strange that the author of the above paper should not have mentioned plastics at all. Sorting and picking tables seem the obvious outlets for laminated and impregnated sheet made from either paper or, better, wood veneers. Conveying systems—rollers, belts, chains—and even pumps of plastics provide a non-metal system of already proved worth.

The same necessity for "looking round" is present in the dry-cleaning industry where special engineering problems exist, since petroleum distillates and other organic solvents, such as trichlorethylene, are employed. Plastics, unattacked by these, should find an outlet in piping and washers. Generally speaking, it would be advisable to avoid corrodible metal in a dry-cleaning industry where cleanliness, especially the avoidance of spoiling cleaned fabric by rust, would appear to be of first importance. Plastic examining tables, hanging racks, etc., have already been suggested as desirable, yet we believe these apparent advantages have nowhere been introduced.

The refrigerator and ice-making industries, especially those that employ brine, suffer greatly from corrosion, not only because of the all-pervading water employed in the manufacture, but also from condensation. Furthermore, brine attacks iron and steel readily. Yet even the well-known rubber pipe for conveying brine is a rarity in small factories and the use of plastic sheet to prevent general contamination almost unknown. It might yet

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be discovered that plastics, with their low coefficient of heat transfer, may be useful to prevent leakage of cold at special points.

Another obvious field for plastics would seem to be in factories manufacturing or using distilled water and especially the photographic industry where contamination by very small quantities of metal is fatal to the production of film or photographic chemicals. Normally pure tin piping, glass-lined tanks, porcelain vessels, etc., are employed. High initial cost and maintenance is general, so that the use of plastics is more than attractive here.

It would not be too much to say that there is no works in the country where plastics could not be used with advantage. Intelligent observation and understanding of plastics is all that is required.

Synthetic Resins for Water Softening.

Experiments carried out at the Chemical Research Laboratory, Teddington, in 1936 and 1937, by Sir Gilbert Morgan and others showed that certain types of synthetic resin, particularly those made with some of the natural tannins, such as sulphited quebracho, possessed interesting base- and acid-exchange properties, which could be usefully exploited in softening water. Thus a sulphited quebracho formaldehyde resin was found to possess base-exchange properties and a resin made by reacting *m*-phenylenediamine with formaldehyde acid-exchange properties. By using these two different types of resin, the base-exchange first and the acid second, all the temporary and permanent hardness salts can be removed from water.

In addition to the ability of these high molecular resins of softening water at least one of them, the *m*-phenylenediamine resin, has the unique property of being able to remove sodium fluoride from water. This, incidentally, is important as some natural waters are known to contain small quantities of fluoride which is responsible for certain types of dental decay. The main disadvantage of these resin exchanges is that some of them are slightly soluble in water and cannot, therefore, be employed where no organic matter of any kind must be allowed to contaminate the water. It is possible that this is only a temporary setback and that when the range of exchange resins is enlarged some will be found suitable for drinking waters.

A writer in *Chem. Fabrik.*, January 1940, p. 30, gives an inter-

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esting account of the use of synthetic resin exchanges for treating highly saline water from the river Saale used for feeding boilers working at 675 lb. per sq. in. The writer summarises the advantages of resin exchanges as follows :

1. A fourfold increase in throughput per unit volume.
2. Lower resistance to flow, enabling deeper exchange-beds to be used, due to the higher efficiency of coarser-grained material.
3. Improved chemical resistance of the resin exchange, which will now function with water up to 9.5 pH.
4. Effective softening at higher temperatures.
5. Increased life of the exchanger material.

The writer points out that possibly the greatest advantage is the ability of the resin to be adapted to suit almost any prevailing condition, and this is of considerable importance to both the engineer and chemist.

CHAPTER VI

THE ELECTRICAL INDUSTRY

SYNTHETIC resins are now being produced which possess most of the properties required for their successful exploitation in the electrical field.

For general applications, such as switches, plugs, adaptors, lamp-holders, radio and telephone components, magneto and coil parts, meter cases and instrument parts, domestic electrical appliances, etc., phenol-formaldehyde resin powders fulfil most requirements as it is available in the ordinary wood-filled grade, fabric-filled for high impact uses and mineral-filled for high heat resistance, etc. Ordinary grades of phenol-formaldehyde resins can be used for applications where temperatures up to 140° C. are experienced.

The urea-formaldehyde paper- or wood-filled resins find similar applications to the phenolic resins, but they possess the advantage of being available in white and pastel shades, in translucent and opaque colours. They also possess a greater resistance to tracking than the phenolics and are thus extensively employed as switch-bases, which were at one time made of porcelain. On the debit side, however, the urea resins are not suitable for use at temperatures in the vicinity of 100° C. and show a marked decline in electrical properties at elevated temperatures. Their moisture absorption figures are also higher than the phenol-formaldehyde resins.

The cellulose esters possess a high impact strength but only moderately good electrical properties, coupled with a poor resistance to heat. Polystyrol, on the other hand, is mechanically somewhat weaker than cellulose acetate, but its electrical properties are vastly superior and it possesses an extremely low loss factor which is very considerably lower than porcelain. The water absorption figure of this resin is also exceptionally low, but, like cellulose acetate, although rather better in this respect, it is unsuit-

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able for use at elevated temperatures, the figure usually specified being about 70°C. , that is, some 20° above that of acetate.

Laminated sheet or tube is, on the whole, a material of outstanding value on account of its great mechanical strength, resistance to high temperatures, reasonably low moisture absorption and good electrical properties. This form of plastic is extensively used in the electrical industry for important constructions, such as carbon circuit breakers, linestarters and contactors, instrument panels, switchboards, etc. The advantage of laminated material is that it is very robust and may be machined in the same way as brass with ordinary tools. Generally speaking, the electrical properties of laminated paper are very similar to mouldings of wood-filled phenolic resin, except that the power factor of the laminated sheet is very much lower than the phenolic moulding.

The above remarks are broad and may be considered as being capable of considerable modification. It should be remembered that practically all the different types of plastics are capable of adaptation and the manufacturer can, within reasonable limits, produce a grade to suit most requirements. In many cases the nature of the filler plays a great part in determining the final properties and in others the nature and percentage of plasticiser. Plastic materials are not static and one of their chief advantages is their fluidity and adaptability.

Apart from the use of plastics for the more widely known electrical applications, the newer vinyl polymers and now the ethylene polymers are being extensively used in place of rubber and even lead for special corrosion-resisting cable sheathing. Commercial varieties now being used for this purpose include the mixed vinyl polymers, such as Koroseal, Mipolam, Igelit and the new I.C.I. polymer, Polythene. These new sheathing materials can be readily extruded and are highly resistant to oxidation and oil.

The table opposite, giving the most important electrical properties of the different types of plastics now available for the electrical goods manufacturer, shows at a glance the main differences between the various synthetic resins.

Phenol-Formaldehyde Mouldings.

For the majority of electrical applications demanding a material possessing good mechanical strength, electric strength and insula-

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Type of Resin.	Specific Gravity.	Moisture Absorption (24 hrs.).	Volume Resistivity (cm. cube, million ohms).	Dielectric Strength (60 cycles).	Dielectric Constant (60 cycles).	Dielectric Constant (10 ⁶ cycles).	Power Factor (60 cycles).	Power Factor (10 ⁶ cycles).
Wood-flour-filled phenolic resin	1.34-1.52	0.2-0.6	10-12	300-500	5-12	4.5-8	0.040-0.300	0.035-0.1
Fabric-filled phenolic resin	1.37-1.40	1.0-1.3	9-11	300-450	5-10	4.5-6	0.080-0.300	0.04-0.1
Mineral-filled phenolic resin	1.70-2.09	0.01-0.3	9-10	250-400	5-20	4.5-20	0.100-0.300	0.005-0.1
Laminated phenol resin	1.34-1.55	0.5	10-13	150-1,300	4.4-6.5	3.6-7		0.02-0.08
Urea paper filled.	1.48-1.50	1.0-2.0	13	300-400	6.6	6	0.034-	0.01-0.03
Cast phenolic resin	1.27-1.32	0.01-0.5	9-14	300-450	5-10	5-7	0.025	0.01-0.045
Acetate	1.27-1.63	2.8-3.0	12	800-850	5.8-6	4.4-4.6	0.042-0.058	0.038-0.042
Vinyl	1.34	0.05-0.15	14	600-700		4		0.0175-
Acrylate	1.18	0.3	15	480	4-6	2.8	0.060-0.080	0.02
Styrene	1.06	0.00	18	500-700	2.6-	2.6	0.0003	0.0001
Hard rubber	1.12-1.80	0.02	12-15	250-900	2.8	3		0.03-0.008

Physical Properties of Chief Plastics.

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tion resistance coupled with low moisture absorption and good dimensional stability, phenolic mouldings are in every way suitable for use up to about 140°C . They do not, however, except in very special grades, possess complete freedom from "tracking," especially under damp or humid conditions, nor are they suitable for high-frequency radio and short-wave work where ceramics and, lately, the polystyrols are used on account of their extremely low loss factor.

Phenol-formaldehyde mouldings offer many advantages to the electrical manufacturer, apart from those mentioned above. These advantages may be briefly summarised as follows :

1. Available on a mass-production scale in shapes and sizes normally difficult and expensive to fabricate in any other dielectric.
2. Mouldings can be produced complete with metal inserts and with insertions for screws, bolts, etc., ready for quick and labour-saving assembly.
3. Mouldings available at reasonably high degree of accuracy ; plus or minus $\frac{2}{1000}$ in. is not uncommon with moulders specialising in electrical goods.
4. When taken from the press the mouldings require very little finishing. The flash has to be removed and perhaps the edges filed.
5. Phenolic moulding powder is very adaptable and grades are available to suit most special requirements. There is, for instance, the standard wood-flour-filled grade for the general run of mouldings, fabric-filled grade for high impact strength mouldings and mineral-filled for high heat resistance and very low moisture absorption.

The field of phenol-formaldehyde mouldings is broadly covered by B.S.S. 771 and deals with five types or grades of material :

Type G	General type
Type GX	Improved general type
Type MS	Medium shock-resistant type
Type HS	High shock-resistant type
Type HR	Heat-resistant type

Although no mention is made of fillers, presumably Type G and